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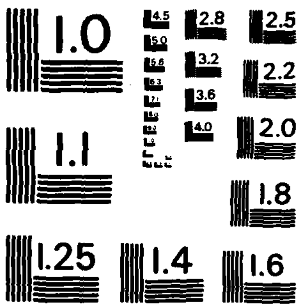


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FINAL REPORT

# DIAGNOSIS AND MANAGEMENT OF DEPLOYED ADULTS WITH CHEST PAIN

by


Lee Goldman, M.D., M.P.H.

Brigham and Women's Hospital

75 Francis Street

Boston, MA 02115

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We prospectively tested the accuracy of our own computer-derived algorithm and the prior computer-derived model of Dr. Timothy de Dombal for predicting whether patients with acute chest pain were having myocardial infarctions. Our model performed significantly better than the de Dombal model; in patients who are most analogous to deployed Navy personnel in terms of age and prior history of ischemic heart disease, our model performed better than the physicians who actually saw the same patients. We conclude that our computer-derived algorithm may be appropriate for adoption in the deployed setting.

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# FINAL REPORT, CHEST PAIN STUDY

## DATA ACQUISITION AND MANAGEMENT

Between October 1980 and April 1982, we prospectively evaluated every patient over the age of 25 who entered the Brigham and Women's Hospital Emergency Room with a chief complaint of chest pain that was not explained by obvious local trauma or by clear chest x-ray abnormalities. A total of 599 patients were entered and subjected to detailed data verification. All data forms were reviewed by the principal investigator, and any questionable items were subjected to impartial review by three physicians who were not aware of the patient's diagnosis or other data. Using an identical protocol, a nurse reviewed the records of another 301 patients who were admitted to the Brigham and Women's Hospital between October 1979 and August 1980 and who otherwise met our study criteria. This latter validation set was added in order to increase the number of patients with myocardial infarction to allow for better testing of the multivariate models, and it resulted in a total sample of 900 patients, 199 of whom had acute myocardial infarctions. The data form that we used is attached as Appendix A, and the publication resulting from this study, "A Computer-Derived Protocol to Aid in the Diagnosis of Emergency Room Patients with Acute Chest Pain" (1), explains our methods in more detail and is enclosed as Appendix B.

## DATA ANALYSIS

The data gathered in this study served for the prospective testing of two models which purport to be able to identify which patients with acute chest pain are having myocardial infarction. First, we evaluated the accuracy of Timothy de Dombal's sequential Bayesian model using the likelihood ratios that he supplied to the United States Navy. Because the results of his study were not provided to us until after our study was well under way, not every one of his potential predictive variables were included in our data set. A detailed review of these missing variables reveals that virtually all of them were tested in our previous work at Yale-New Haven Hospital and found not to be helpful. Secondly, these missing variables were found useful by Dr. de Dombal for differentiating pneumonia from cardiac pain, but not for differentiating myocardial ischemia from myocardial infarction. Because we believe that the differential of infectious pneumonia from acute myocardial infarction is a rather simple process that has been performed without difficulty by previous investigators, and because not a single patient in our experience was admitted for a suspicion of myocardial infarction and then was found instead to have bacterial pneumonia, we believe that the exclusion of such variables has virtually no effect on the clinically relevant issues at hand.

The statistical techniques used by Dr. de Dombal have presumably been described in his own final report, and we see no need to review them here. Our model, which was derived on a set of 482 patients at Yale-New Haven Hospital before the beginning of the present grant, utilized the recursive partitioning technique. This method, which has recently been developed, essentially constructs an empirical decision tree. The full details of this multivariate analytic technique are reviewed in the Methods Section of Appendix B.

## RESULTS

### RECURSIVE PARTITIONING MODEL:

The recursive partitioning model with the electrocardiogram is shown in Figure 1. In the entire prospective testing set at the Brigham and Women's Hospital, this model achieved a sensitivity of 90%, a specificity of 65% and a positive predictive value of 42% (see Table 1A) when applied to all patients of

PROSPECTIVE EVALUATION

ALL SUBJECTS

(n = 899)

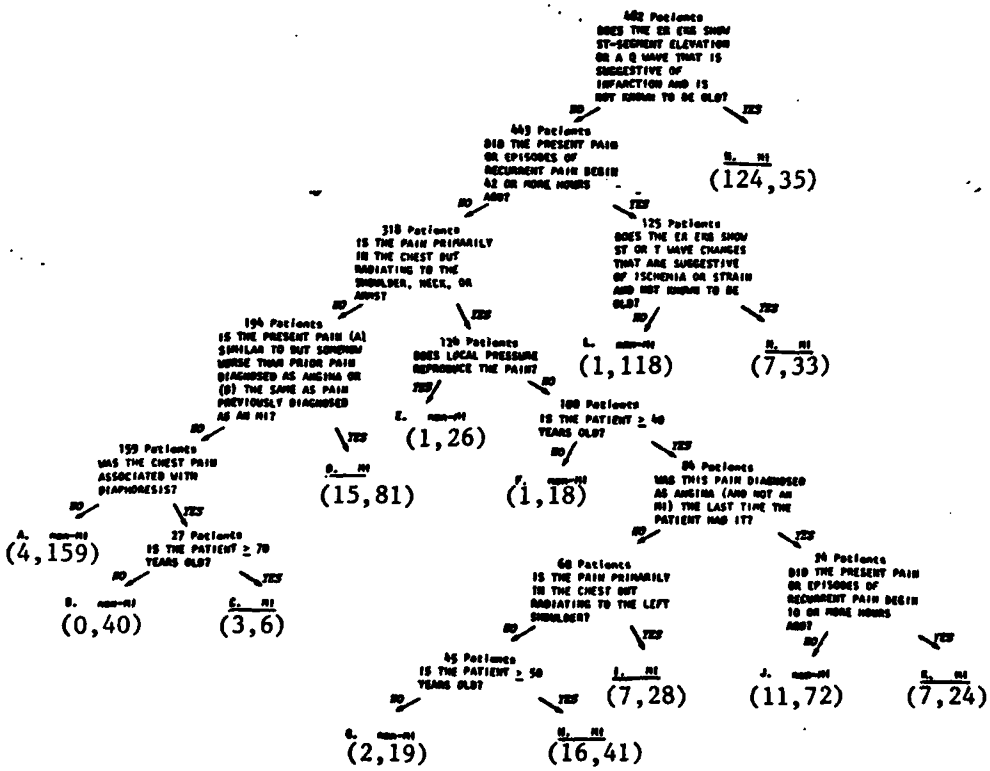



Figure 1 : Performance of the recursive partitioning model with the EKG on all 899 patients. For each subgroup, the first number indicates the number of myocardial infarction patients and the second number indicates the number of non-myocardial infarction patients within that terminal subgroup.

PROSPECTIVE EVALUATION

MALE SUBJECTS

(n = 455)

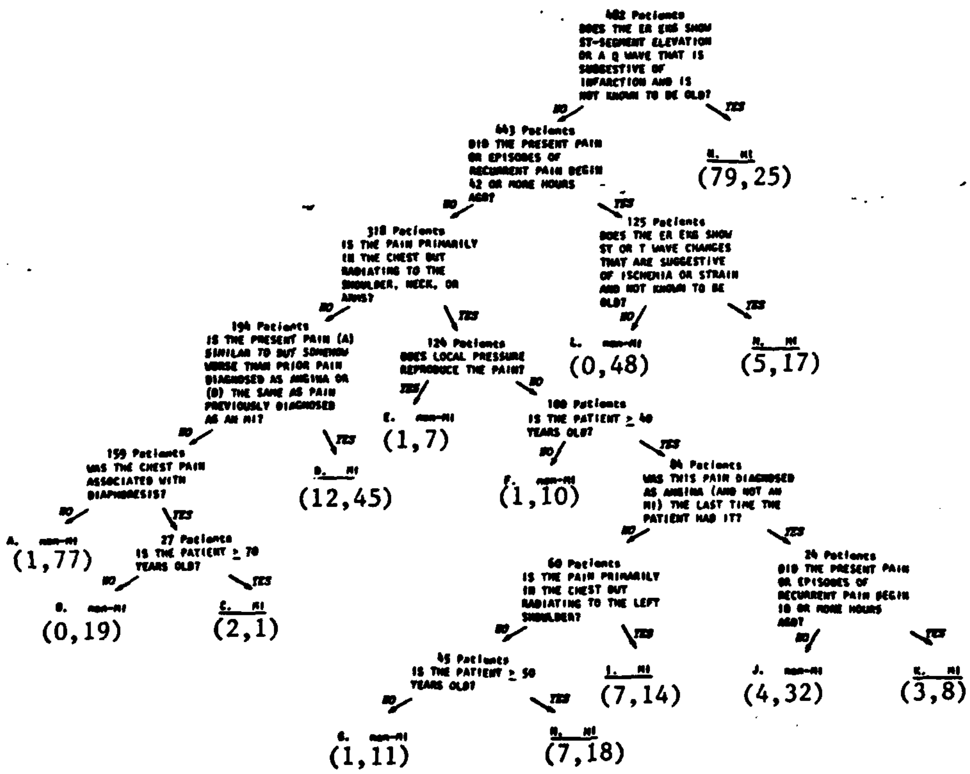



Figure 2: The performance of the recursive partitioning model with the EKG on all males (n=455). For each subgroup, the first number indicates the number of myocardial infarction patients and the second number indicates the number of non-myocardial infarction patients within that terminal subgroup.

PROSPECTIVE EVALUATION

MALE SUBJECTS

< 60 YEARS OLD

NO PREVIOUS CAD

( n = 159)

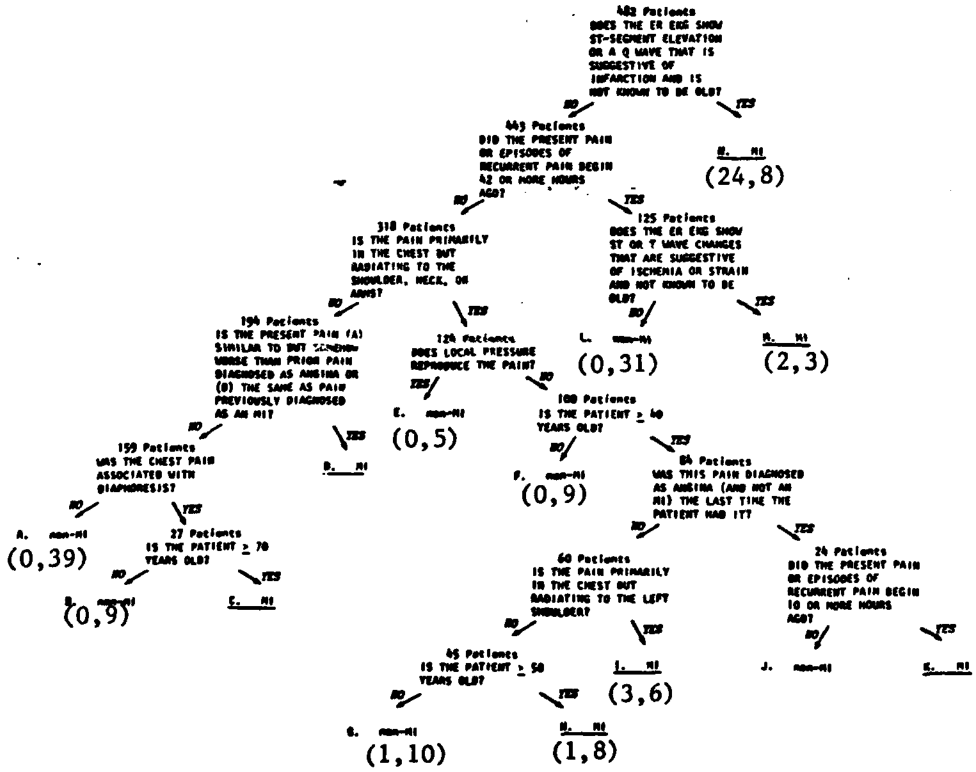



Figure 4: The performance of the recursive partitioning model with the EKG on all males under the age of 60 without a prior history of angina or myocardial infarction (n=159). For each subgroup, the first number indicates the number of myocardial infarction patients and the second number indicates the number of non-myocardial infarction patients within that terminal subgroup.

PROSPECTIVE EVALUATION

MALE AND FEMALE SUBJECTS

< 60 YEARS OLD

NO PREVIOUS CAD

( n = 331)

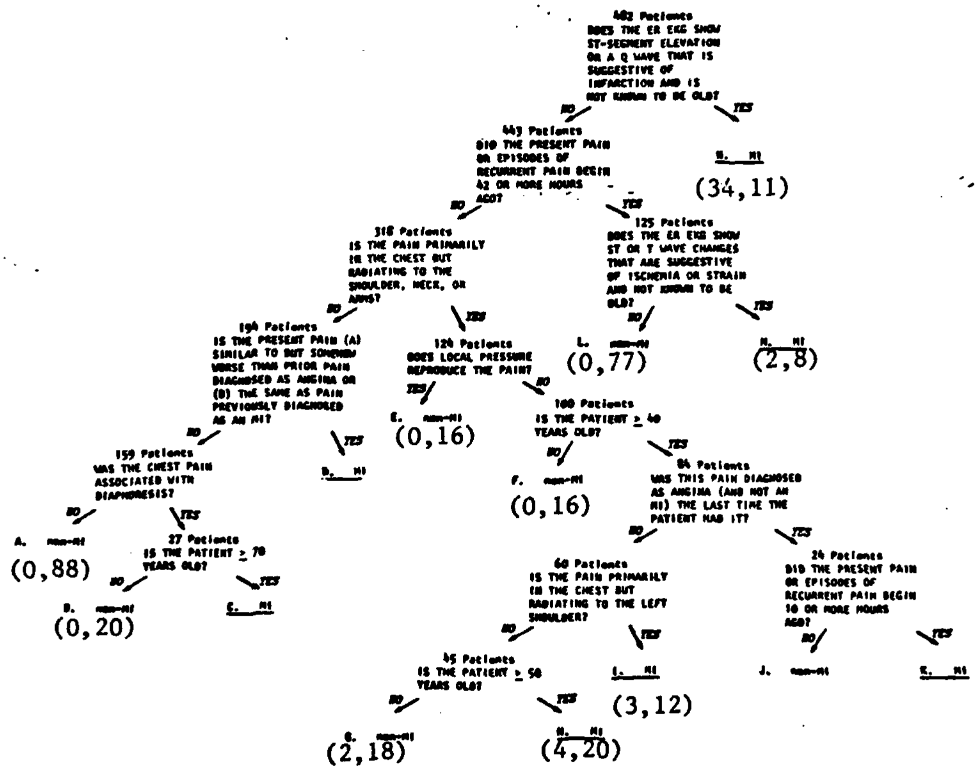



Figure 5: The performance of the recursive partitioning model with the EKG on all males under the age of 60 without a prior history of angina or myocardial infarction (n=331). For each subgroup, the first number indicates the number of myocardial infarction patients and the second number indicates the number of non-myocardial infarction patients within that terminal subgroup.

TABLE 1:

PERFORMANCE OF RECURSIVE PARTITIONING MODEL WITH THE EKG

A. All BWH Patients ( n = 899 )

| | | MODEL: MI | MODEL: NO MI | |
|---|---|---|---|---|
| TRUTH | MI | 179 | 20 | 199 |
| | NO MI | 248 | 452 | 700 |
| | | 427 | 472 | 899 |

$$\text{SENSITIVITY} = \frac{179}{199} = .90$$

$$\text{SPECIFICITY} = \frac{452}{700} = .65$$

$$\text{POSITIVE PREDICTIVE VALUE} = \frac{179}{427} = .42$$

B. All BWH Males ( n = 455 )

| | | MODEL: MI | MODEL: NO MI | |
|---|---|---|---|---|
| TRUTH | MI | 115 | 8 | 123 |
| | NO MI | 128 | 204 | 332 |
| | | 243 | 212 | 455 |

$$\text{SENSITIVITY} = \frac{115}{123} = .93$$

$$\text{SPECIFICITY} = \frac{204}{332} = .61$$

$$\text{POSITIVE PREDICTIVE VALUE} = \frac{115}{243} = .47$$

TABLE 1 (continued):

PERFORMANCE OF RECURSIVE PARTITIONING MODEL WITH THE EKG

C. BWH Males, < 60 years old, ( n = 250 )

| | | MODEL | | |
|---|---|---|---|---|
| | | MI | NO MI | |
| TRUTH | MI | 49 | 4 | 53 |
| | NO MI | 59 | 138 | 197 |
| | | 108 | 142 | 250 |

$$\text{SENSITIVITY} = \frac{49}{53} = .92$$

$$\text{SPECIFICITY} = \frac{138}{197} = .70$$

$$\text{POSITIVE PREDICTIVE VALUE} = \frac{49}{108} = .45$$

D. BWH Males, < 60 years old, no prior angina or MI ( n = 159 )

| | | MODEL | | |
|---|---|---|---|---|
| | | MI | NO MI | |
| TRUTH | MI | 30 | 1 | 31 |
| | NO MI | 25 | 103 | 128 |
| | | 55 | 104 | 159 |

$$\text{SENSITIVITY} = \frac{30}{31} = .97$$

$$\text{SPECIFICITY} = \frac{103}{128} = .80$$

$$\text{POSITIVE PREDICTIVE VALUE} = \frac{30}{55} = .55$$

TABLE 1 (continued):

PERFORMANCE OF RECURSIVE PARTITIONING MODEL WITH THE EKG

E. BWH Males and Females, < [illegible]0 years old, no prior angina or MI

| | | MODEL: MI | MODEL: NO MI | |
|---|---|---|---|---|
| TRUTH | MI | 43 | 2 | 45 |
| | NO MI | 51 | 235 | 286 |
| | | 94 | 237 | 331 |

$$\text{SENSITIVITY} = \frac{43}{45} = .96$$

$$\text{SPECIFICITY} = \frac{235}{286} = .82$$

$$\text{POSITIVE PREDICTIVE VALUE} = \frac{43}{94} = .46$$

all ages. Of the 20 myocardial infarctions that were missed by this model, 11 (55%) were in subgroup J, which is relevant only to patients with a prior history of angina. Table 1, sections B, C, D, and E show the performance of this same model on various subsets of patients in the Brigham and Women's Hospital testing phase.

Note that the model performed especially well in the subgroups of particular interest to the United States Navy. In Table 1D, we see that the model had a sensitivity of 97%, a specificity of 80% and a positive predictive value of 55% for predicting myocardial infarction in males under the age of 60 who had no prior history of angina or myocardial infarction. The model's performance was nearly as good if we consider both males and females who are under age 60 and have no prior history of angina or myocardial infarction (see Table 1E).

By comparison, we tried several different recursive partitioning trees that included all the same clinical data that were available for the construction of the preceding tree, except that the data from the electrocardiogram was excluded. The performance of the non-EKG recursive partitioning model was not nearly as good as the performance of the model with the electrocardiogram (see Table 2, Sections A, B, C, D, and E). In the overall sample, the sensitivity of the non-EKG recursive partitioning model was 66%, specificity was 68%, and positive predictive value 37% (see Table 2A). For the group of most interest, namely males under the age of 60 without a prior history of myocardial infarction or angina, the sensitivity of the non-EKG recursive partitioning model was 74%, specificity 76%, and positive predictive value 43% (see Table 2D). For all males and females under age 60 without a prior history of angina or myocardial infarction, the sensitivity was 71%, specificity 77%, and positive predictive value 32% (see Table 2E).

When the model with the EKG was compared to the model without the EKG, the

TABLE 2:

PERFORMANCE OF RECURSIVE PARTITIONING MODEL WITHOUT THE EKG

A. All BWH Patients ( n = 894 )

| | | MODEL: MI | MODEL: NO MI | |
|---|---|---|---|---|
| TRUTH | MI | 130 | 67 | 197 |
| | NO MI | 220 | 477 | 697 |
| | | 350 | 544 | 894 |

$$\text{SENSITIVITY} = \frac{130}{197} = .66$$

$$\text{SPECIFICITY} = \frac{477}{697} = .68$$

$$\text{POSITIVE PREDICTIVE VALUE} = \frac{130}{350} = .37$$

B. BWH Males ( n = 452 )

| | | MODEL: MI | MODEL: NO MI | |
|---|---|---|---|---|
| TRUTH | MI | 83 | 38 | 121 |
| | NO MI | 108 | 223 | 331 |
| | | 191 | 261 | 452 |

$$\text{SENSITIVITY} = \frac{83}{121} = .69$$

$$\text{SPECIFICITY} = \frac{223}{331} = .67$$

$$\text{POSITIVE PREDICTIVE VALUE} = \frac{83}{191} = .43$$

TABLE 2 (continued):

PERFORMANCE OF RECURSIVE PARTITIONING MODEL WITHOUT THE EKG

C. BWH Males, < 60 years old, (n = 250)

| | | MODEL | | |
|---|---|---|---|---|
| | | MI | NO MI | |
| TRUTH | MI | 32 | 20 | 52 |
| | NO MI | 58 | 140 | 198 |
| | | 90 | 160 | 250 |

$$\text{SENSITIVITY} = \frac{32}{52} = .62$$

$$\text{SPECIFICITY} = \frac{140}{198} = .71$$

$$\text{POSITIVE PREDICTIVE VALUE} = \frac{32}{90} = .36$$

D. BWH Males, < 60 years old, no prior angina or MI (n = 159)

| | | MODEL | | |
|---|---|---|---|---|
| | | MI | NO MI | |
| TRUTH | MI | 23 | 8 | 31 |
| | NO MI | 31 | 97 | 128 |
| | | 54 | 105 | 159 |

$$\text{SENSITIVITY} = \frac{23}{31} = .74$$

$$\text{SPECIFICITY} = \frac{97}{128} = .76$$

$$\text{POSITIVE PREDICTIVE VALUE} = \frac{23}{54} = .43$$

TABLE 2 (continued):

PERFORMANCE OF RECURSIVE PARTITIONING MODEL WITHOUT THE EKG

E. BWH Males and females, < 60 years old, no prior angina or MI

(n = 331)

| | | MODEL: MI | MODEL: NO MI | |
|---|---|---|---|---|
| TRUTH | MI | 32 | 13 | 45 |
| | NO MI | 67 | 219 | 286 |
| | | 99 | 232 | 331 |

$$\text{SENSITIVITY} = \frac{32}{45} = .71$$

$$\text{SPECIFICITY} = \frac{219}{286} = .77$$

$$\text{POSITIVE PREDICTIVE VALUE} = \frac{32}{99} = .32$$

sensitivity of the former was significantly higher for males who were less than 60 years old without a prior history of angina or MI (P=0.012) as well as for all males and females who were under age 60 without a prior history of angina or MI (P=0.002). For the males under age 60 without a prior history of myocardial infarction or angina, the addition of the EKG to the recursive partitioning model allowed for the identification of seven additional myocardial infarction patients, while at the same time reducing the number of false positive diagnoses from 31 to 25. For all patients under the age of 60 without a prior history of myocardial infarction or angina, the addition of the EKG to the recursive partitioning model permitted the identification of 11 additional myocardial infarction patients, while at the same time reducing the number of false positive predictions from 67 to 51. Thus, the addition of the electrocardiogram increases sensitivity significantly, while at the same time slightly increasing specificity.

Although we have not performed detailed cost benefit analyses of the electrocardiogram, it is clear that it results in a substantial increase in both sensitivity and specificity. Because of the enormous expense of even one false-positive diagnosis that results in the emergency evacuation of a patient who is not truly at risk, we believe that it is fairly clear that it is worthwhile to have the capability of performing and reading an electrocardiogram on board. We believe that the amount of sophistication required to read the electrocardiogram is small. If baseline electrocardiograms were available on crew members, the margin of error for the reading by the corpsmen on board the submarine could be reduced even further. Unfortunately, we cannot estimate the precise value of having a baseline electrocardiogram on all these patients without performing field testing with your corpsmen.

PERFORMANCE OF THE PHYSICIANS:

It is especially noteworthy to compare the performance of the recursive partitioning algorithm to the actual performance of the Brigham and Women's Hospital emergency room physicians' admission decisions (see Table 3A-E). In prospective testing on the 159 males less than 60 years old with no prior history of angina or myocardial infarction (see Table 3D), the physicians' admission decisions to intensive care had a sensitivity of 97%, a specificity of 66%, and a positive predictive value of 41%. Compared to the prospective validation of the recursive partitioning algorithm on the same patients, the admission decisions of the physicians were significantly less specific (66% vs. 80%, P=0.015) at the identical sensitivity of 97%.

For all males and females who are less than 60 years old and had no prior history of angina or myocardial infarction, the physicians' admission decisions had a sensitivity of 98%, a specificity of 74%, and a positive predictive value of 37% (see Table 3E). Thus, the physicians' sensitivity was insignificantly higher than that of the algorithm's prospective performance on the same patients (44 of 45 myocardial infarction patients were admitted compared to 43 of 45 who are identified by the algorithm, P=N.S.), but the algorithm was significantly more specific (82% vs. 74%, P=0.0007). Another way of analyzing this difference would be to say that the physicians admitted 25 more patients than would have been recommended for admission by the algorithm, and only 1 of these 25 patients had a myocardial infarction.

Based on the prospective performance of the computer algorithm on these patients, we believe that in the two subgroups of patients that are most pertinent to the U.S. Navy, the recursive partitioning model has actually outperformed the physicians who saw the same patients in the emergency room. This striking result, which could not be achieved in the version of the recursive

TABLE 3:

PERFORMANCE OF EMERGENCY ROOM PHYSICIANS

A. All BWH Patients (n = 900)

| | | ADMIT TO CCU/ICU | | |
|---|---|---|---|---|
| | | YES | NO | |
| TRUTH | MI | 189 | 10 | 199 |
| | NO MI | 323 | 378 | 701 |
| | | 512 | 388 | 900 |

$$\text{SENSITIVITY} = \frac{189}{199} = .95$$

$$\text{SPECIFICITY} = \frac{378}{701} = .54$$

$$\text{POSITIVE PREDICTIVE VALUE} = \frac{189}{512} = .37$$

B. BWH Males (n = 456)

| | | ADMIT TO CCU/ICU | | |
|---|---|---|---|---|
| | | YES | NO | |
| TRUTH | MI | 116 | 7 | 123 |
| | NO MI | 180 | 153 | 333 |
| | | 296 | 160 | 456 |

$$\text{SENSITIVITY} = \frac{116}{123} = .94$$

$$\text{SPECIFICITY} = \frac{153}{333} = .46$$

$$\text{POSITIVE PREDICTIVE VALUE} = \frac{116}{296} = .39$$

TABLE 3 (continued):

C. BWH Males < 60 years old (n = 251)

| | | ADMIT TO CCU/ICU YES | NO | |
|---|---|---|---|---|
| TRUTH | MI | 49 | 4 | 53 |
| | NO MI | 95 | 103 | 198 |
| | | 144 | 107 | 251 |

$$\text{SENSITIVITY} = \frac{49}{53} = .92$$

$$\text{SPECIFICITY} - \frac{103}{198} = .52$$

$$\text{POSITIVE PREDICTIVE VALUE} = \frac{49}{144} = .34$$

TABLE 3 (continued):

D. BWH Males, < 60 years old, no prior angina or MI (n = 159)

| | | ADMIT TO CCU/ICU YES | NO | |
|---|---|---|---|---|
| TRUTH | MI | 30 | 1 | 31 |
| | NO MI | 44 | 84 | 128 |
| | | 74 | 85 | 159 |

$$\text{SENSITIVITY} = \frac{30}{31} = .97$$

$$\text{SPECIFICITY} = \frac{84}{128} = .66$$

$$\text{POSITIVE PREDICTIVE VALUE} = \frac{30}{74} = .41$$

E. BWH Males and Females, < 60 years old, no prior angina or MI (n= 331)

| | | ADMIT TO CCU/ICU YES | NO | |
|---|---|---|---|---|
| TRUTH | MI | 44 | 1 | 45 |
| | NO MI | 75 | 211 | 286 |
| | | 119 | 212 | 331 |

$$\text{SENSITIVITY} = \frac{44}{45} = .98$$

$$\text{SPECIFICITY} = \frac{211}{286} = .74$$

$$\text{POSITIVE PREDICTIVE VALUE} = \frac{44}{119} = .37$$

partitioning algorithm that did not include the electrocardiogram, suggests that the full recursive partitioning algorithm may be especially beneficial for deployed adults in the military setting.

PERFORMANCE OF THE DE DOMBAL MODEL:

Based on the factors shown in Table 4, we analyzed the accuracy of the de Dombal model for predicting diagnosis in the Brigham and Women's Hospital patients. In the subgroups of most interest to the Navy, the de Dombal model did not perform nearly as well as the recursive partitioning model (Table 5A-E). For example, when looking at males less than 60 years old without a prior history of angina or MI, and taking as the model prediction the diagnosis with the highest probability, the de Dombal model with the SGOT had a sensitivity of 26%, a specificity of 87%, and a positive predictive value of 32% for predicting myocardial infarction (Table 5D). This sensitivity, which we believe to be grossly inadequate, was also statistically significantly (P<0.0001) lower than the sensitivity of the recursive partitioning model. As also shown in Table 5D-2, the de Dombal model without the SGOT performed marginally better than the de Dombal model with the SGOT, but it still had a sensitivity of only 52%, which was statistically significantly (P<0.0001) and clinically significantly lower than the sensitivity of the recursive partitioning model with the EKG. The data in Tables 5E-1 and 5E-2, which showed the performance of the de Dombal model with and without the SGOT for males and females who are less than 60 years old without a prior history of angina or MI, again demonstrate that the model without the SGOT performed slightly better than the model with the SGOT. More importantly, however, both models had sensitivities that were clinically and statistically significantly (both P's <0.0001) lower than that of the recursive partitioning model, despite positive predictive values that were lower than the

TABLE 4: VARIABLES INCLUDED IN DE DOMBAL MODEL

Age < 30
Age 30-39
Age 40-49
Age ≥ 50
Pain duration < 1 hour
Pain duration 1-2 hours
Pain duration 2-4 hours
Pain duration 4-12 hours
Pain duration > 12 hours
Pain primarily in center of chest
Pain primarily across chest
Pain primarily on left side
Pain primarily on right side
Pain - other
Pain radiates
Pain does not radiate
Pain radiates to left arm
Pain radiates to right arm
Pain radiates to both arms
Pain radiates to back
Pain radiates to shoulder
Pain radiates to neck
Pain radiates to jaw
Pain radiates - other
Numbness is present
Numbness is not present
Pain is pleuritic
Pain is relieved by nitroglycerin
Dyspnea not present
Dyspnea present
Cough present
Cough not present
History of previous chest pain
No history of previous chest pain
Sweating present
Sweating not present
Systolic blood pressure ≤ 100
Systolic blood pressure 101-120
Systolic blood pressure 121-140
Systolic blood pressure 141-160
Systolic blood pressure > 160
Diastolic blood pressure ≤ 70
Diastolic blood pressure 71-80
Diastolic blood pressure 81-90
Diastolic blood pressure 91-100
Diastolic blood pressure > 100
Chest sounds normal
Chest has rales
SGOT < 50
SGOT 51-100
SGOT 101-200
SGOT > 200

TABLE 5:

PERFORMANCE OF DE DOMBAL MODEL

A. All Patients (n = 900)

(1) De Dombal Model With SGOT

| | | MI | NO MI | |
|---|---|---|---|---|
| TRUTH | MI | 70 | 129 | 199 |
| | NO MI | 76 | 625 | 701 |
| | | 146 | 754 | 900 |

$$\text{SENSITIVITY} = \frac{70}{199} = .34$$

$$\text{SPECIFICITY} = \frac{625}{701} = .89$$

$$\text{POSITIVE PREDICTIVE VALUE} = \frac{70}{146} = .48$$

(2) De Dombal Model Without SGOT

| | | MI | NO MI | |
|---|---|---|---|---|
| TRUTH | MI | 68 | 131 | 199 |
| | NO MI | 108 | 593 | 701 |
| | | 176 | 724 | 900 |

$$\text{SENSITIVITY} = \frac{68}{199} = .34$$

$$\text{SPECIFICITY} = \frac{593}{701} = .85$$

$$\text{POSITIVE PREDICTIVE VALUE} = \frac{68}{176} = .39$$

TABLE 5 (continued):

B. All BWH Males (n = 456)

(1) De Dombal Model With SGOT

| | | MI | NO MI | |
|---|---|---|---|---|
| | MI | 38 | 85 | 123 |
| TRUTH | | | | |
| | NO MI | 33 | 300 | 333 |
| | | 71 | 385 | 456 |

$$\text{SENSITIVITY} = \frac{38}{123} = .31$$

$$\text{SPECIFICITY} = \frac{300}{333} = .90$$

$$\text{POSITIVE PREDICTIVE VALUE} = \frac{38}{71} = .54$$

(2) De Dombal Model Without SGOT

| | | MI | NO MI | |
|---|---|---|---|---|
| | MI | 39 | 84 | 123 |
| TRUTH | | | | |
| | NO MI | 47 | 286 | 333 |
| | | 86 | 370 | 456 |

$$\text{SENSITIVITY} = \frac{39}{123} = .32$$

$$\text{SPECIFICITY} = \frac{286}{333} = .86$$

$$\text{POSITIVE PREDICTIVE VALUE} = \frac{39}{86} = .45$$

TABLE 5 (continued):

C. BWH Males, < 60 years old, (n = 251)

(1) De Dombal Model With SGOT

| | | MI | NO MI | |
|---|---|---|---|---|
| TRUTH | MI | 11 | 42 | 53 |
| | NO MI | 20 | 178 | 198 |
| | | 31 | 220 | 251 |

$$\text{SENSITIVITY} = \frac{11}{53} = .21$$

$$\text{SPECIFICITY} = \frac{178}{198} = .90$$

$$\text{POSITIVE PREDICTIVE VALUE} = \frac{11}{31} = .35$$

(2) De Dombal Model Without SGOT

| | | MI | NO MI | |
|---|---|---|---|---|
| TRUTH | MI | 16 | 37 | 53 |
| | NO MI | 29 | 169 | 198 |
| | | 45 | 206 | 251 |

$$\text{SENSITIVITY} = \frac{16}{53} = .30$$

$$\text{SPECIFICITY} = \frac{169}{198} = .85$$

$$\text{POSITIVE PREDICTIVE VALUE} = \frac{16}{45} = .36$$

TABLE 5 (continued):

D. Males less than 60 years old without prior angina or MI (n = 159)

(1) De Dombal Model with SGOT

| | | MI | NOT MI | |
|---|---|---|---|---|
| TRUTH | MI | 8 | 23 | 31 |
| | NOT MI | 17 | 111 | 128 |
| | | 25 | 134 | 159 |

$$\text{SENSITIVITY} = \frac{8}{31} = .26$$

$$\text{SPECIFICITY} = \frac{111}{128} = .87$$

$$\text{POSITIVE PREDICTIVE VALUE} = \frac{8}{25} = .32$$

(2) De Dombal Model without SGOT

| | | MI | NOT MI | |
|---|---|---|---|---|
| TRUTH | MI | 16 | 15 | 31 |
| | NOT MI | 28 | 100 | 128 |
| | | 44 | 115 | 159 |

$$\text{SENSITIVITY} = \frac{16}{31} = .52$$

$$\text{SPECIFICITY} = \frac{100}{128} = .78$$

$$\text{POSITIVE PREDICTIVE VALUE} = \frac{16}{44} = .36$$

TABLE 5 (continued):

E. Males and females less than 60 years old without prior angina or MI

(1) De Dombal Model with SGOT

| | | MI | NOT MI | |
|---|---|---|---|---|
| TRUTH | MI | 14 | 31 | 45 |
| | NOT MI | 22 | 264 | 286 |
| | | 36 | 295 | 331 |

$$\text{SENSITIVITY} = \frac{14}{45} = .31$$

$$\text{SPECIFICITY} = \frac{264}{288} = .92$$

$$\text{POSITIVE PREDICTIVE VALUE} = \frac{14}{36} = .39$$

(2) De Dombal Model without SGOT

| | | MI | NOT MI | |
|---|---|---|---|---|
| TRUTH | MI | 23 | 22 | 45 |
| | NOT MI | 44 | 242 | 286 |
| | | 67 | 264 | 331 |

$$\text{SENSITIVITY} = \frac{23}{45} = .51$$

$$\text{SPECIFICITY} = \frac{242}{288} = .84$$

$$\text{POSITIVE PREDICTIVE VALUE} = \frac{23}{67} = .34$$

recursive partitioning model.

## RECEIVER OPERATING CHARACTERISTIC CURVE ANALYSIS:

The relative performances of the various models can also be shown using receiver operating characteristic curve analyses. Figures 6 through 10 show the relative performances of the recursive partitioning model with the EKG, the recursive partitioning model without the EKG, the de Dombal model with the SGOT, and the de Dombal model without the SGOT for predicting myocardial infarction. In this analysis, the successive points on the recursive partitioning models represent the inclusion of successive subgroups based on the predicted probability of infarction in the testing sample. For the two recursive partitioning models, these curves represent a true prospective validation of the successive risk groups as identified in the retrospectively derived model. For the de Dombal model curves, the successive points represent the inclusion of patients with lower and lower estimated probabilities of acute myocardial infarction, regardless of whether acute myocardial infarction was or was not the diagnosis with the highest probability. Thus, these four curves represent a true prospective validation of the probabilities that were available from the data that were used to derive these four models.

Visual inspection of Figures 6 through 10 indicates that the recursive partitioning model with the EKG performs better than any of the other three curves at all clinically relevant sensitivities. The recommended use of the recursive partitioning model with the EKG (as noted in Table 1A-E) had a significantly higher specificity than could be achieved at the same sensitivity by either of the two de Dombal models for all five sets of patients. The superior performance of this recursive partitioning model in subgroups D and E is further demonstrated in Table 6.

FIGURE 6

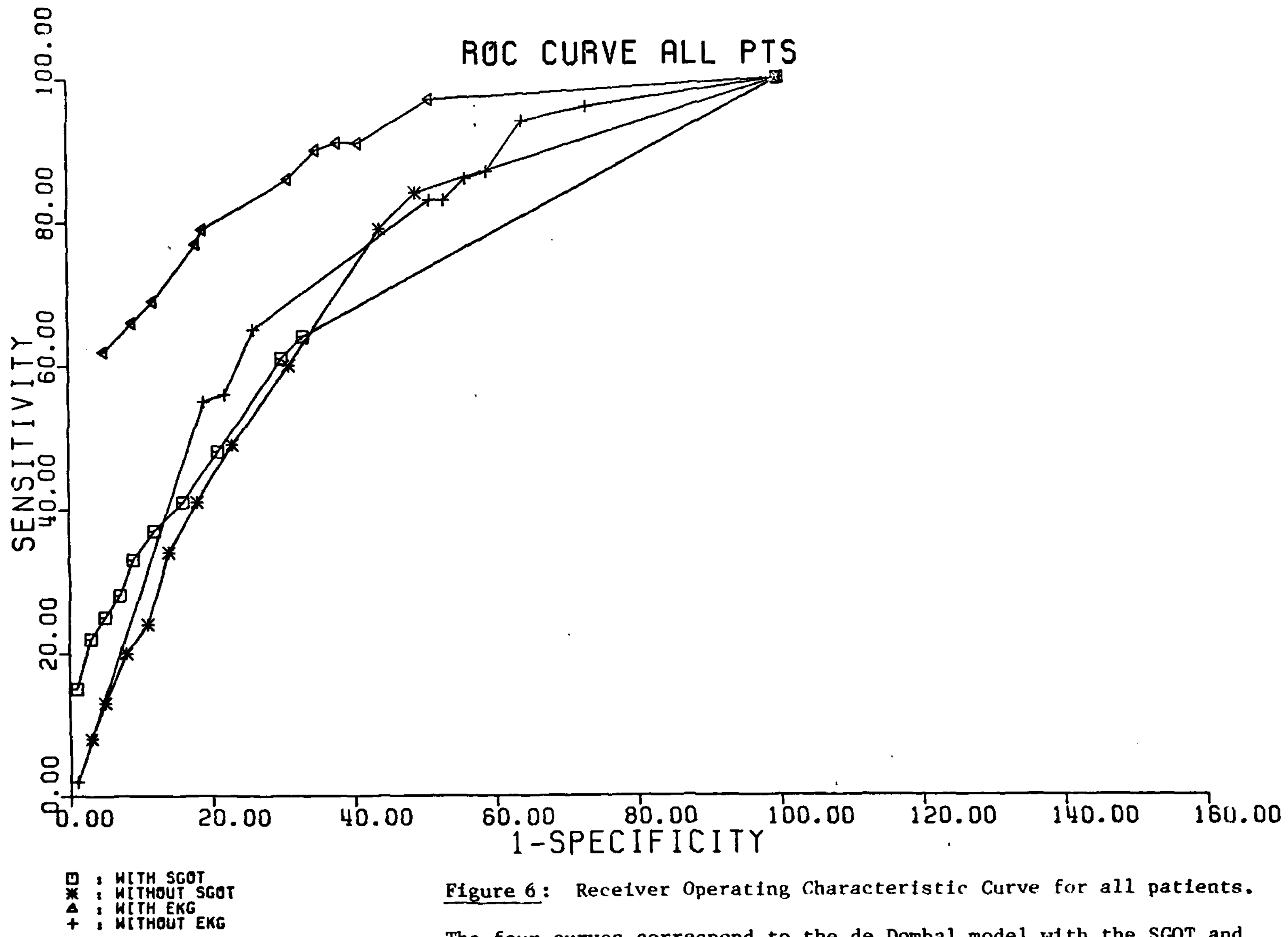
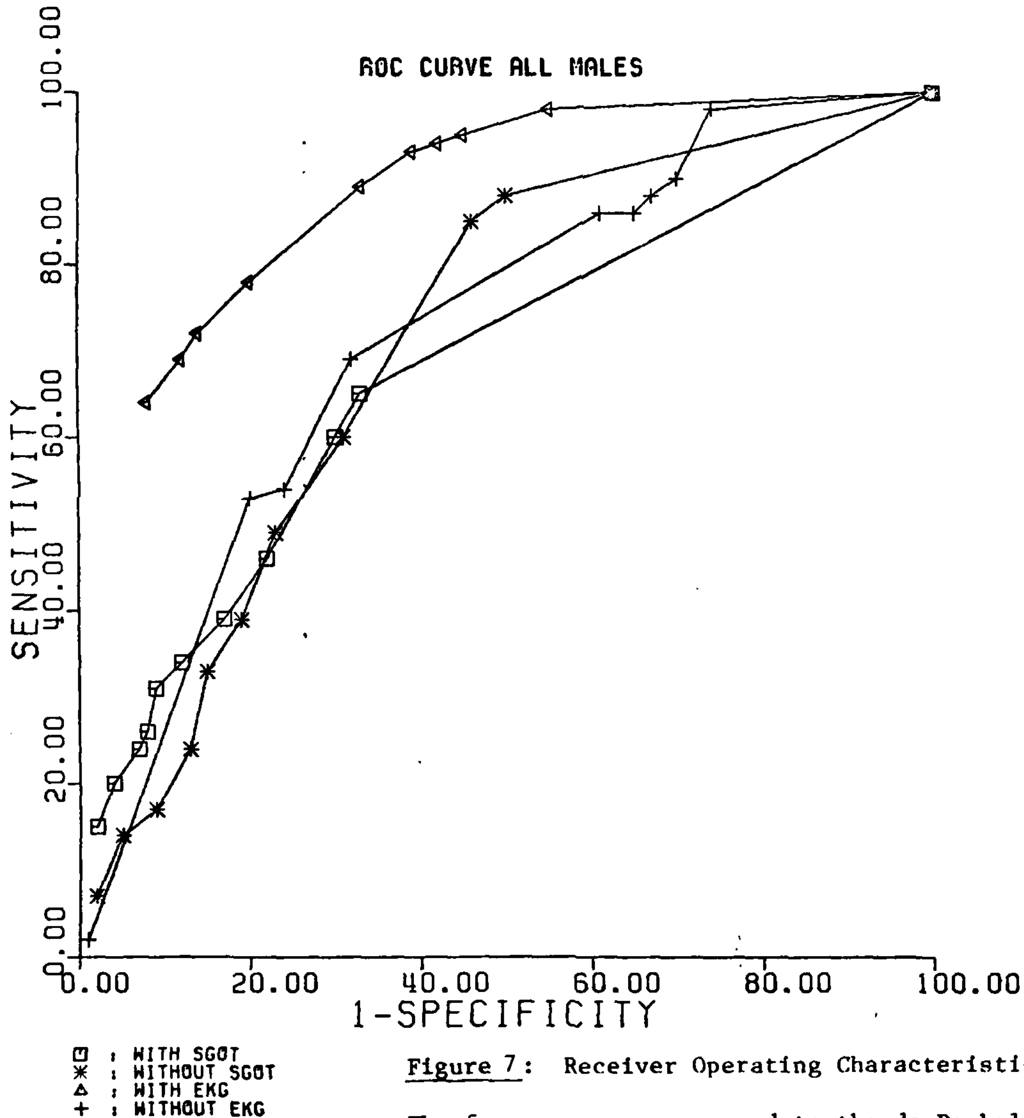



Figure 6: Receiver Operating Characteristic Curve for all patients. The four curves correspond to the de Dombal model with the SGOT and without the SGOT, and to the recursive partitioning model with the EKG and without the EKG.

FIGURE 7




<u>Figure 7</u>: Receiver Operating Characteristic Curve for all males. The four curves correspond to the de Dombal model with the SGOT and without the SGOT, and to the recursive partitioning model with the EKG and without the EKG.

FIGURE 8

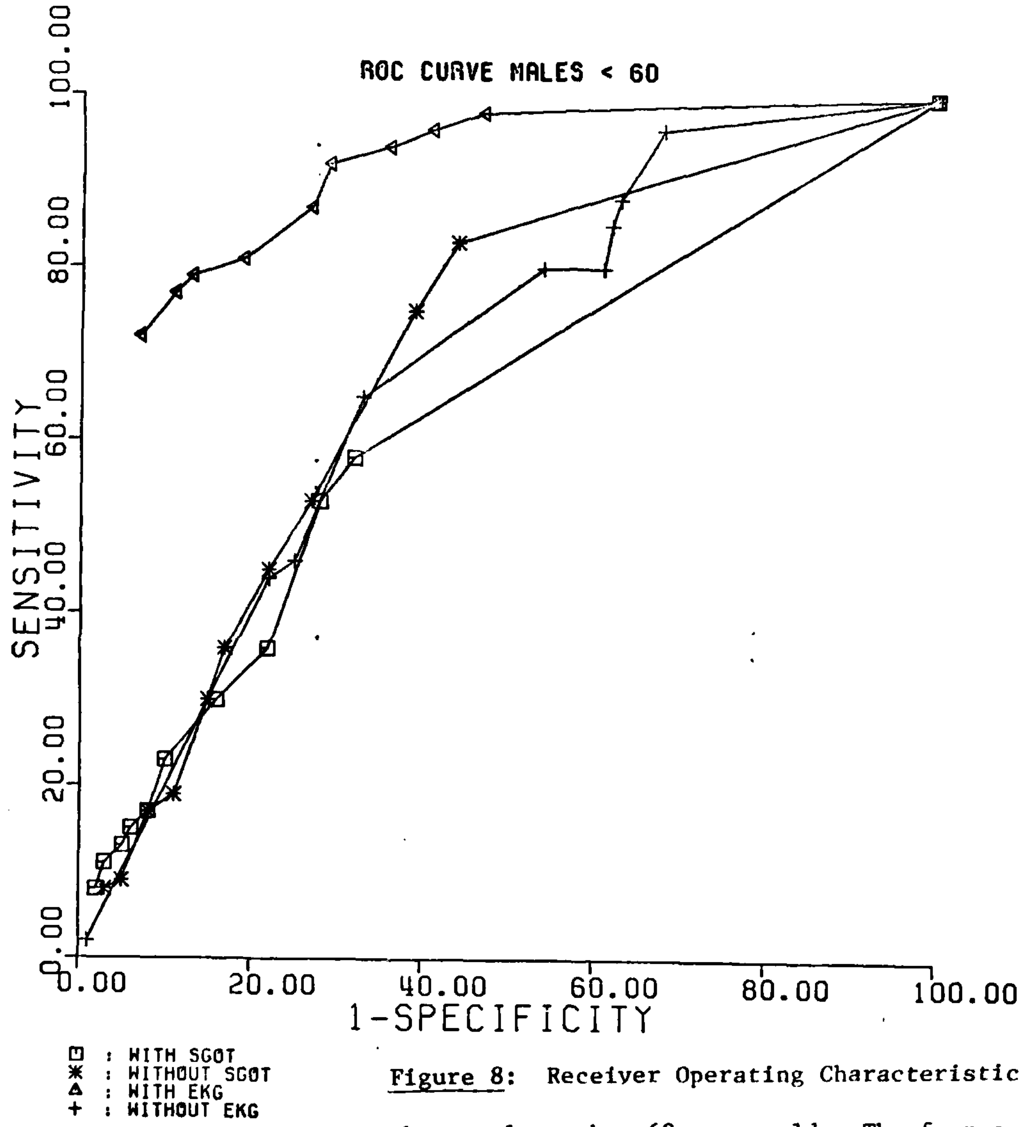



Figure 8: Receiver Operating Characteristic Curve for all males who are less than 60 years old. The four curves correspond to the de Dombal model with the SGOT and without the SGOT, and to the recursive partitioning model with the EKG and without the EKG.

FIGURE 9

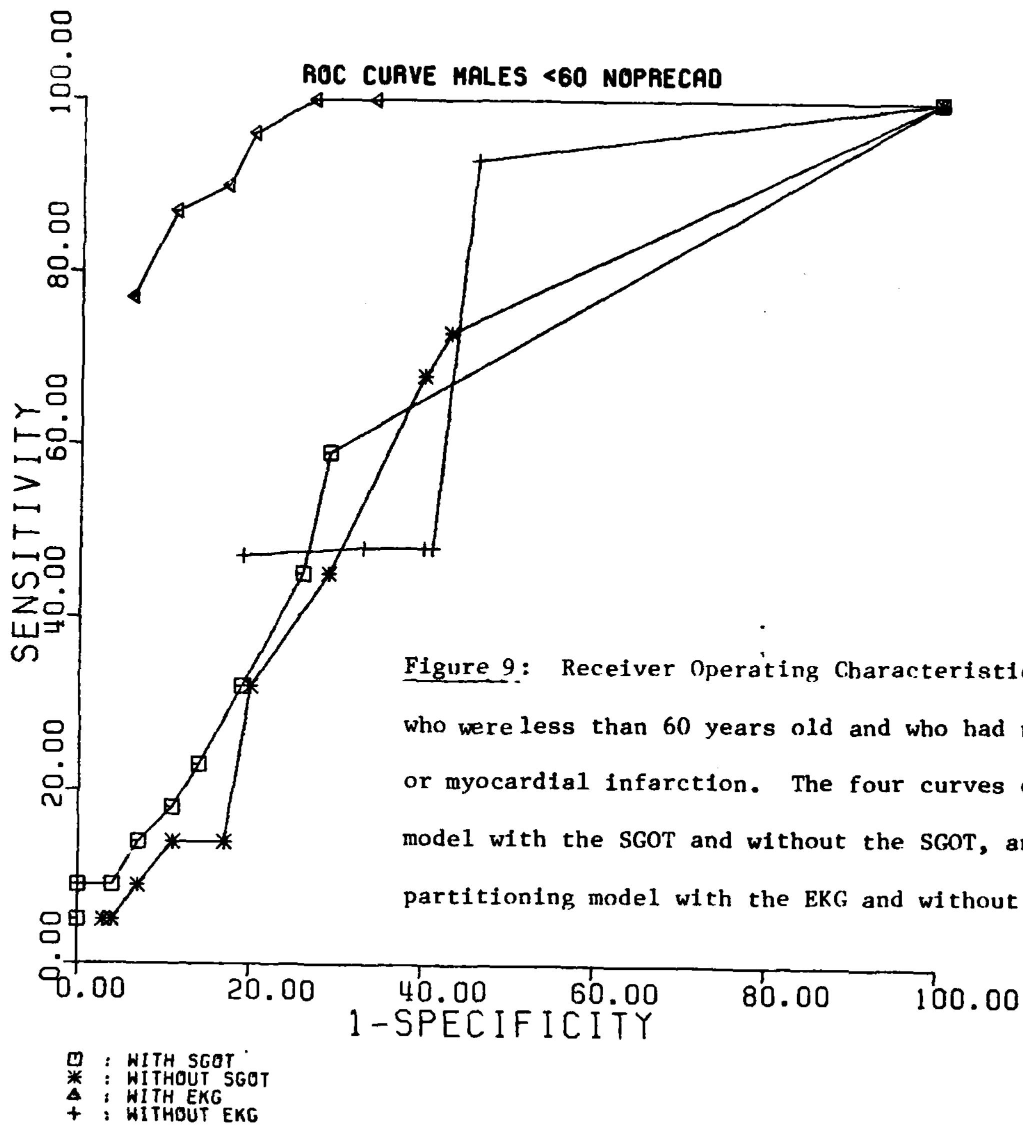



Figure 9: Receiver Operating Characteristic Curve for all males who were less than 60 years old and who had no prior history of angina or myocardial infarction. The four curves correspond to the de Dombal model with the SGOT and without the SGOT, and to the recursive partitioning model with the EKG and without the EKG.

FIGURE 10

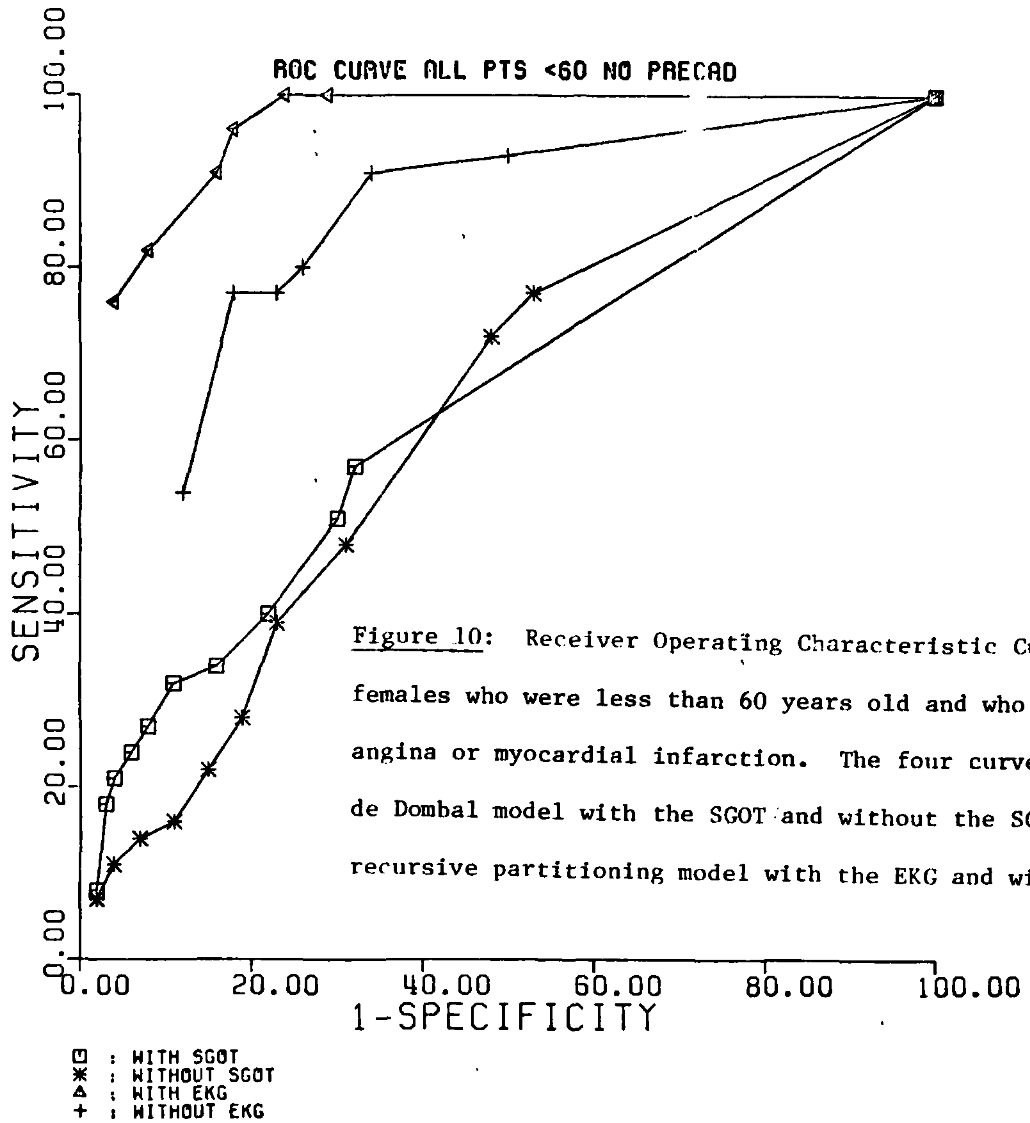



Figure 10: Receiver Operating Characteristic Curve for all males and females who were less than 60 years old and who had no prior history of angina or myocardial infarction. The four curves correspond to the de Dombal model with the SGOT and without the SGOT, and to the recursive partitioning model with the EKG and without the EKG.

TABLE 6:

RECURSIVE PARTITIONING (RP) MODEL WITH THE EKG VERSUS DE DOMBAL (DD) MODELS

Males less than 60 years old without a prior history of angina or MI

(RP Model with EKG has sensitivity of 97%)

At this sensitivity

| | RP with EKG | DD with SGOT | DD without SGOT |
|---|---|---|---|
| specificity | .80 | .46* | .51* |
| positive predictive value | .55 | .30* | .32* |

*significantly lower than for RP with EKG, $P < 0.01$

Males and females less than 60 years old without a prior history of angina or MI

(RP Model with EKG has sensitivity of 96%)

At this sensitivity

| | RP with EKG | DD with SGOT | DD without SGOT |
|---|---|---|---|
| specificity | .82 | .56* | .52* |
| positive predictive value | .46 | .25* | .24* |

*significantly lower than for RP with EKG, $P < 0.001$

Visual inspection of Figures 6 to 10 also demonstrates that the SGOT adds little to the de Dombal model.

INTEGRATION OF RECURSIVE PARTITIONING MODEL (WITH THE EKG) WITH THE PHYSICIANS

Although the computer algorithm with the EKG was the single best predictor of myocardial infarction in patients under the age of 60 without prior angina or infarction, an integration of the computer algorithm with the physicians' decisions was more accurate than either one alone (see Table 7). Note that if both the algorithm predicted myocardial infarction and the physician admitted the patient to intensive care, 66% of males and 60% of all males and females had infarctions. By comparison, if the model predicted infarction but the physicians did not admit the patients to intensive care or if the physicians admitted the patients to intensive care despite the fact that the model did not predict infarction, only about 4% of patients had infarction. If neither the model predicted infarction nor the physicians admitted the patients to intensive care, no patients had myocardial infarctions. Thus, a combination of the model and the physicians' decisions identified a very high risk group, a group with no risk, and also an intermediate group with a risk of 4%-5%. In some settings it may be argued that these latter patients would be appropriate for special handling, but in a deployed setting where an evacuation would be costly in many respects, evacuation of patients with a 4%-5% risk of infarction would usually not be recommended.

## DISCUSSION

We have previously reported the early prospective results of our computer algorithm in a broad selection of patients who presented to a university hospital emergency room with acute chest pain (1). In that overall analysis, the computer algorithm performed about as well as the physicians. However, our

TABLE 7:

INTEGRATION OF RECURSIVE PARTITIONING ALGORITHM ( WITH THE EKG) WITH THE MDs DECISIONS

A. Males less than 60 years old without prior angina or MI (n=159)

| | # Patients | # MIs | % MIs |
|---|---|---|---|
| Model predicts MI and MDs admit to CCU/ICU | 44 | 29 | 66% |
| Model predicts MI and MDs do not admit to CCU/ICU OR Model predicts non-MI and MDs admit to CCU/ICU | 41 | 2 | 5% |
| Model predicts non-MI and MDs do not admit to CCU/ICU | 74 | 0 | 0% |

B. Males and Females less than 60 years old without prior angina or MI

| | # Patients | # MIs | % MIs |
|---|---|---|---|
| Model predicts MI and MDs admit to CCU/ICU | 70 | 42 | 60% |
| Model predicts MI and MDs do not admit to CCU/ICU OR Model predicts non-MI and MDs admit to CCU/ICU | 73 | 3 | 4% |
| Model predicts non-MI and MDs do not admit to CCU/ICU | 188 | 0 | 0% |

computer algorithm's diagnostic predictions were least accurate in patients with a history of angina or myocardial infarction, and it was in this group that the physicians performed slightly better. This relative disadvantage of the algorithm compared to the physicians is not relevant if the population to be considered has no prior history of angina or infarction and is under the age of 60. In the present analysis, the computer algorithm performed significantly better than the physicians in this latter group of patients, who are reasonably similar to the kinds of patients who might be encountered in a deployed military setting.

Previous analyses by us (1) and by Pozen and colleagues (2) have suggested that a combination of computer algorithms with physicians may perform better than either one alone. Certainly, the present data suggest that such an integration of doctors and the algorithm can identify three risk groups. However, our data are even more encouraging, in that the computer algorithm itself was significantly more accurate than the physicians in a prospective test. We do not suggest that physicians who see patients in a deployed military setting should follow the algorithm and ignore their clinical judgement; but our results suggest that when the two disagree, it is more likely that the algorithm is correct. In settings where medical care must be delivered by non-physician personnel, the algorithm may permit diagnoses to be as accurate as in settings where physicians are present. This algorithm therefore deserves further prospective testing in adults in a deployed setting, with the possibility that it might become an integral part of the management of such patients.

## CONCLUSIONS

In our prospective testing, the de Dombal models performed poorly. In those patients who were most pertinent to the U.S. Navy, our recursive partitioning model with the EKG performed better than the physicians who saw the same patients. The EKG criteria used by our model are rather simple and easy, and we believe they will be reproducible especially if a prior EKG is available for comparison.

## REFERENCES

1. Goldman L, Weinberg M, Weisberg M, et al. A computer-derived algorithm to aid in the diagnosis of emergency room patients with acute chest pain. N Engl J Med 1982; 307:588-96.

2. Pozen MW, D'Agostino RB, Mitchell JB, et al. The usefulness of a predic'ive instrument to reduce inappropriate admissions to the coronary care unit. Ann Intern Med 1980; 92:238-42.

## APPENDICES

Appendix A: Data Form

Appendix B: Goldman L, Weinberg M, Weisberg M, et al. A computer-derived algorithm to aid in the diagnosis of emergency room patients with acute chest pain. N Engl J Med 1982; 307:588-96.

1. E.R. VISIT DATE ______________
DAY MTH YR

2. BWH # ______________

I. DEMOGRAPHIC:

1. PATIENT'S NAME: LAST ______________ FIRST ______________

ADDRESS: ______________ PHONE: ______________

______________

EMPLOYER: ______________ PHONE ______________

REGULAR M.D. (IF ANY) WHO WOULD CARE FOR HEART PROBLEMS: ______________

RELATIVE OR FRIEND TO CONTACT: ______________

RELATIVE OR FRIEND'S ADDRESS: ______________

2. SOCIAL SECURITY NUMBER: ______________ PHONE: ______________

3. AGE: (IN YEARS) ________ DATE OF BIRTH: __________

4. SEX: M=MALE F=FEMALE ________

II. HISTORY OF PRESENT ILLNESS:

5. HOW MANY HOURS AGO DID THE PAIN OR EPISODES OF PAIN START ____ ____ (use 99 for 99+ hrs.)

6. HOW LONG IN DURATION WAS THE LONGEST EPISODE OF CHEST PAIN THAT PROMPTED ER VISIT?

6.1 ________hours

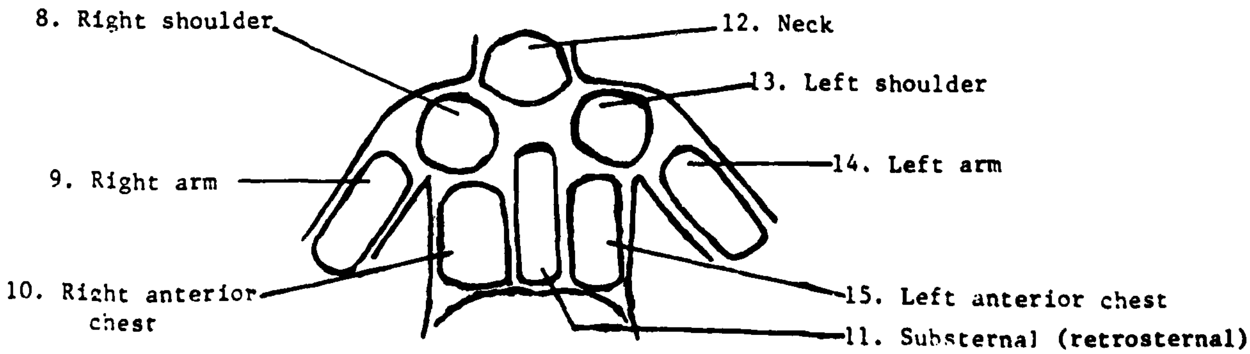
6.2 ________minutes

7. QUALITY OF PAIN: (CIRCLE ONE NUMBER ONLY)

1=pressing, pressure, crushing
2=sharp, stabbing
3=burning
4=ache
5=indigestion, gas
6=numbness
7=indescribable
8=other (describe)

8. to 15. DESCRIBE SEVERITY OF PAIN ON THE DIAGRAMMED AREAS

Put a "1" in pain's major location (where it is most severe). Put "2" in other locations where pain radiates or is less severe.




Other: 16. back_____ 17. legs_____ 18. abdomen_____ 19. other_____

20. to 22. ARE THERE ANY ASSOCIATED SYMPTOMS?

| | 1=no | 2=yes, resolved | 3=yes, persists |
|---|---|---|---|
| 20. shortness of breath | | | |
| 21. diaphoresis | | | |
| 22. cough | | | |

| 23., 24. WAS PAIN: | 1=no | 2=yes, partly | 3=yes, mainly or fully |
|---|---|---|---|
| 23. pleuritic | | | |
| 24. positional | | | |

| 25., 26. DID PAIN RESPOND TO: | 1=didn't try | 2= no relief | 3= partial relief | 4= full relief |
|---|---|---|---|---|
| 25. TNG or other nitrates | | | | |
| 26. antacids | | | | |

27. Has patient had similar chest pain in the past? 1=yes 2=no

28. Has patient ever received medical attention for similar pain? 1=yes 2=no

28.1 If yes, what was diagnosis on most recent such visit (choose one)

1=Not diagnosed/Unknown 2=MI 3=Angina 4=Other (Specify________

28.2 If most recent diagnosis is Angina, is current pain

1=Worse 2=About the same 3=Not as bad

compared to previous episodes?

28.3 If Worse than last episode, how so (check any that apply):

____ 1. More severe

____ 2. Longer duration

____ 3. Lack of response to rest/meds/or whatever was previously helpful

____ 4. More frequent

28.4 Worse in other way: ________________________________

## III. PAST MEDICAL HISTORY AND RISK FACTORS:

29. to 35. DOES PATIENT HAVE A HISTORY OF:

| | 1=no | 2=uncertain | 3=yes |
|---|---|---|---|
| 29. MI | | | |
| 30. angina | | | |
| 31. CHF | | | |
| 32. hypertension | | | |
| 33. elevated cholesterol | | | |
| 34. parents or sibs with M.I. or sudden death when < 65 y.o. | | | |
| 35. other | | | |

36. IS PATIENT A SMOKER: 1=never 2=prior smoker, not now smoking 3=smoker at present 4=can't be found on chart

37. DOES PATIENT HAVE A HISTORY OF DIABETES MELLITUS?: 1=no 2=yes, diet Rx only 3=oral meds 4=yes, insulin 5=can't be found on chart

## IV. PHYSICAL EXAMINATION:

38. ER BLOOD PRESSURE: systolic ____________ 39. diastolic ____________

40. RALES: 1=none 2=yes, probably not cardiac 3=yes, cardiac

41. If cardiac, what of % way up lung fields? ______________________

42. CHEST TENDERNESS TO PALPATION: 1=no 2=yes, does not reproduce chest pain 3=yes, and reproduces chest pain 4=no comment on chart

43. DOES THE PATIENT HAVE A PERICARDIAL RUB?: 1=no 2=yes

## V. ELECTROCARDIOGRAM AND CHEST X-RAY:

44. ARE OLD EKG'S AVAILABLE FOR REVIEW DURING PATIENT'S TIME IN ER? 1=no 2=yes

44.1 If yes, is present EKG changed compared to last available EKG? 1=no 2=yes

45. WOULD YOU CLASSIFY THE PRESENT ER EKG AS: (circle highest number that applies)

1=normal
2=non-specific ST or T wave changes
3=abnormal (e.g. LBBB, RBBB, LAD, abnormal PR, VPC's, PAC's, AF, etc.), but no ischemia
4=ischemia, strain, or MI but all old
5=ischemia or strain, not known to be old
6=probable transmural MI (Q's and/or ST elevation) which appears to be new

46. WAS CHEST X-RAY DONE? 1=yes 2=no

46.1 HEART SIZE BY X-RAY: 1=normal 2=borderline 3=enlarged

47. LUNG FIELDS ON X-RAY: 1=no CHF 2=vascular redistribution, CHF 3=pulmonary edema

VI. ER DECISIONS:

48. IF THE PATIENT'S CHEST PAIN WOULD NOT REQUIRE ADMISSION, IS THERE ANOTHER PROBLEM THAT WOULD REQUIRE ADMISSION? 1=yes 2=no

48.1 IF YES, SPECIFY ______________________________

BASED ON YOUR EVALUATION, WHAT IS THE PROBABILITY (FROM 0% TO 100%) OF:

49. ACUTE MYOCARDIAL INFARCTION ------------------------------------→ _____

50. NEW ONSET OR WORSENED ANGINA WITHOUT MYOCARDIAL INFARCTION ------→ _____

51. OTHER ----------------------------------------------------------→ _____

"100% TOTAL"

52. WHAT IS THE MOST LIKELY "OTHER" IN THIS PATIENT? (CIRCLE NONE OR ONE)

1=stable angina
2=pericarditis
3=GI pain
4=musculoskeletal pain
5=pleuritis or pneumonia
6=trauma
7=other (please specify) ____________________ ____________________

53. IF THE DECISION WERE YOURS AND YOURS ALONE, WHAT WOULD YOUR DECISION BE IN TERMS OF HOSPITAL ADMISSION? (CIRCLE ONE ONLY)

1=admit to CCU or ICU
2=admit to step-down unit with monitor
3=admit to step-down unit without monitor
4=admit to regular ward bed
5=send home

54. WHAT IS PATIENT'S DISPOSITION? (CIRCLE ONE ONLY)

1=admit to CCU or ICU
2=admit to step-down unit with monitor
3=admit to step-down unit without monitor
4=admit to regular ward bed
5=send home

(SPECIFY ADMISSION LOCATION) ____________________

55. WHAT M.D. WAS PRIMARILY RESPONSIBLE FOR DECIDING ON THE ER DISPOSTION?

______________________________

56. NAME OF HOUSE OFFICER WHO FILLED OUT THIS FORM ____________________

THANK YOU FOR COMPLETING THIS FORM.
PLEASE PLACE THIS IN THE LARGE RED "CHEST PAIN STUDY" NOTEBOOK LOCATED ON THE SHELF OVER THE COMMON WORK TABLE.

VII. ENZYMES DRAWN DURING HOSPITALIZATION OR AS PART OF THIS STUDY:

ER enzymes

| | Date | Time | SGOT | LDH | CPK | CPK ISOENZYMES | LDH ISOENZYMES |
|---|---|---|---|---|---|---|---|
| 1. | | | | | | | |
| 2. | | | | | | | |
| 3. | | | | | | | |
| 4. | | | | | | | |
| 5. | | | | | | | |

VIII. F/U QUESTIONNAIRE FOR NON-ADMISSION PATIENTS:

Date/Time Initial Visit _________ Date/Time Followup Visit _________ Hours After E.R. Visit _________

57. Is the pain that originally brought you to the ER present?

1. YES _____

Describe how ________________________________________

2. NO _____

How many hours ago did it disappear? _____

58. Do you have any new symptoms?

1. YES _____

What are they? ________________________________________

2. NO _____

59. Have you seen any other doctors for the pain since you came to the E.R.?

1. YES _____

Give details ________________________________________

2. NO _____

## IX. FINAL DIAGNOSIS:

A._____ TRANSMURAL MI (new Q wave of 0.04 second duration)

B._____ SUBENDOCARDIAL MI (SGOT 2x admission or 1½ x normal; or + CPK isoenzymes; or $LDH_1 > LDH_2$ in the absence of other causes).

C._____ UNSTABLE ANGINA (new onset angina or angina that is worse in severity, frequency or duration; or decreased responsiveness to usual angina therapy).

D._____ STABLE ANGINA

E._____ OTHER CARDIAC

F._____ CHF

G._____ VALVULAR HEART DISEASE (specify) ______________________________

H._____ ARRHYTHMIAS

I._____ PERICARDITIS

J._____ OTHER (specify) ______________________________

K._____ GI

L._____ MUSCULOSKELETAL

M._____ TRAUMA

N._____ OTHER (specify) ______________________________

O._____ UKNOWN

## X. EKG:

ER, offical reading (all patients) (Circle one only)

1=normal
2=non-specific ST or T wave changes
3=abnormal (e.g. LBBB, RBBB, LAD, abnormal PR, VPC's, PAC's, AF, etc.), but no ischemia
4=ischemia, strain, or MI but all old
5=ischemia, or strain, not known to be old
6=probable transmural MI (Q's and/or ST elevation) which appears to be new

F/U, official reading (non-admissions only) (Circle one only)

1=normal
2=non-specific ST or T wave changes
3=abnormal (e.g. LBBB, RBBB, LAD, abnormal PR, VPC's, PAC's, AF, etc.), but no ischemia
4=ischemia, strain, or MI but all old
5=ischemia, or strain, not known to be old
6=probable transmural MI (Q's and/or ST elevation) which appears to be new

# SPECIAL ARTICLE

## A COMPUTER-DERIVED PROTOCOL TO AID IN THE DIAGNOSIS OF EMERGENCY ROOM PATIENTS WITH ACUTE CHEST PAIN

LEE GOLDMAN, M.D., M.P.H., MARC WEINBERG, M.D., MONICA WEISBERG, R.N., RICHARD OLSHEN, PH.D., E. FRANCIS COOK, M.S., R. KENT SARGENT, M.D., G. A. LAMAS, M.D., CHARLES DENNIS, M.D., CLYDE WILSON, M.D., LAWRENCE DECKELBAUM, M.D., HARVEY FINEBERG, M.D., PH.D., ROBERT STIRATELLI, PH.D., AND THE MEDICAL HOUSE STAFFS AT YALE–NEW HAVEN HOSPITAL AND BRIGHAM AND WOMEN'S HOSPITAL*

**Abstract** To determine whether data available to physicians in the emergency room can accurately identify which patients with acute chest pain are having myocardial infarctions, we analyzed 482 patients at one hospital. Using recursive partitioning analysis, we constructed a decision protocol in the format of a simple flow chart to identify infarction on the basis of nine clinical factors. In prospective testing on 468 other patients at a second hospital, the protocol performed as well as the physicians. Moreover, an integration of the protocol with the physicians' judgments resulted in a classification system that preserved sensitivity for detecting infarctions, significantly improved the specificity (from 67 per cent to 77 per cent, $P<0.01$) and positive predictive value (from 34 per cent to 42 per cent, $P = 0.016$) of admission to an intensive-care area. The protocol identified a subgroup of 107 patients among whom only 5 per cent had infarctions and for whom admission to non-intensive-care areas might be appropriate.

This decision protocol warrants further wide-scale prospective testing but is not ready for routine clinical use. (N Engl J Med. 1982; 307:588-96.)

CHEST pain is part of the symptom complex of about two thirds of patients admitted to a hospital with acute myocardial infarctions,[1] but the identification of patients whose chest pain represents acute myocardial infarction is among the most difficult problems in clinical medicine. Because of fear of the consequences of missing patients at high risk, emergency room physicians are encouraged to admit patients to "rule out myocardial infarction" if the diagnosis is uncertain. Although this practice increases the number of admissions of patients who do have acute myocardial infarction, it has led to a situation in which as few as 30 per cent of patients admitted to coronary-care units are eventually diagnosed as having acute myocardial infarctions.[2] If the differentiation between acute myocardial infarction and other causes of chest pain could be made more accurate, the quantity of scarce resources spent on unnecessary admissions to the coronary-care unit[3,4] could be substantially reduced.

To derive a protocol to identify myocardial infarction, we studied patients who went to one hospital emergency room with chest pain. We then prospectively tested the protocol on two sets of patients at a second hospital.

*The medical house officers who participated directly in this effort included the following: in 1977 at Yale–New Haven Hospital, Drs. Robert Jarret, Geoffrey Priest, John D'Avella, Mark Millard, Richard Kayne, David Coleman, Stephen Shell, Jeffrey Stem, Daniel Rahn, Robert Schoen, Carl Schoenberger, James Touloukian, Dana Brock, Vincent DiCola, Mark Cullen, Donald Furman, Lee Katz, Kenneth Dobular, Charles Kowal, William Levy, Paula McFadden, Eric Conn, Florence Comite, Clifford Berken, Steven Brody, Joseph Craft, Mark Goldgeier, Jeffrey Hymes, Rex Mahnensmith, Richard Maunder, and Ronald Vender; and in 1980-1981 at Brigham and Women's Hospital, Drs. Adrienne Bentman, Paula Bockenstadt, James Breeling, John Clark, Marc Colb, Douglas Dawley, Susan Day, Andrew Eisenhauer, David Fox, James Garland, David Ginsburg, Bruce Given, David Golan, James Kirshenbaum, Ronald Koenig, Gordon Kritzer, Theodore Krontiris, Risa Lavizzo-Mourey, Thomas Lee, Dennis Loh, Vincent Picozzi, Martha Radford, Celeste Robb-Nicholson, Neal Rosen, Jamie Rosoff, Janet Seltzer, Sandra Skettino, Julia Smith, Julian Solway, Richard Stead, James Stoller, Elizabeth Tam, Ralph Wallerstein, Ronald White, and Richard Wright.

From the Departments of Medicine, Brigham and Women's Hospital, Harvard Medical School, and Yale University School of Medicine; the Center for the Analysis of Health Practices and The Health Sciences Computing Facility, Harvard School of Public Health; and the Department of Mathematics, University of California at San Diego. Address reprint requests to Dr. Goldman at the Department of Medicine, Brigham and Women's Hospital, 75 Francis St., Boston, MA 02115.

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### METHODS

The investigation proceeded in two phases: a training phase at the Yale–New Haven Hospital, during which a decision protocol was developed, and a validation phase at the Brigham and Women's Hospital (in Boston), during which the protocol was applied in the diagnosis of two sets of patients.

#### Phase One, Protocol Development

Between August and November 1977, every patient who was age 30 or above and who went to the Yale–New Haven Hospital emergency room with a chief complaint of anterior, precordial, or left-lateral chest pain unexplained by obvious local trauma or chest-film abnormalities was eligible for this study.

#### Emergency Room

The emergency room intern or resident completed a data form for each patient at a time when the physician had no knowledge of, and thus could not be influenced by, the patient's post-emergency room course. In addition, since blood enzyme measurements were not immediately available, such data could not influence the way the physician recorded information or treated the patient. Historical data included age; sex; marital status; employment status; number of hours since the onset of the pain that prompted the visit to the emergency room; the duration of the present episode of pain; the location of the pain; a qualitative description of the pain; any pleuritic or positional component to the pain; the response to nitroglycerin, antacids, aspirin, or other medications; the presence and presumed cause of any similar earlier pain; shortness of breath, diaphoresis, nausea, palpitations, light-headedness, or syncope; any

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history of myocardial infarction, angina, heart failure or arrhythmias; hypertension, hypercholesterolemia, positive family history, diabetes mellitus, or cigarette smoking; the time of any previous myocardial infarctions; and the present and past worst symptoms of angina and heart failure as identified by the New York Heart Association criteria. All present medications and the amount of nitroglycerin taken during the previous month were recorded. Physical-examination data included systolic and diastolic blood pressures, jugular-venous and carotid-artery pulsations, rales, $S_3$ and $S_4$ gallops, murmurs, chest tenderness, edema, signs of hypoperfusion, and evidence of peripheral arterial disease. The emergency room electrocardiogram (EKG) was recorded and compared with any available earlier EKGs. Any chest x-ray findings such as cardiomegaly, vascular redistribution, and abnormalities of the aorta were recorded. The emergency room physician was also asked to estimate the probability that the patient's chest pain was attributable to acute myocardial infarction and the probability that the pain was attributable to acute myocardial ischemia; for both estimates, the categories were 0 per cent, 1 to 5 per cent, 6 to 24 per cent, 25 to 75 per cent, 76 to 94 per cent, or above 94 per cent. Among 500 consecutive eligible patients, the collection of emergency room data was completed for the 482 patients on whom the first phase was based. The other 18 patients, excluded because house officers did not complete their data forms, were similar to the 482 patients in their ability to give a medical history, ultimate diagnosis, and outcome.

### Follow-up

We obtained follow-up information for 478 (99.2 per cent) of the 482 patients six to 10 months (mean, eight months) after the emergency room visit. Of the four patients who could not be found, one had been admitted to the coronary-care unit with noncardiac chest pain and probable Münchausen's syndrome before having returned home to a distant city. The three others were not admitted to the hospital and could not be contacted although all were local residents; local city and hospital records did not indicate that any of these patients had died. The follow-up questionnaire determined whether any chest-pain syndrome had persisted or recurred and whether the patient had had any physician visits or hospitalizations since the emergency room visit. In addition, all pertinent physician and hospital records were obtained.

### Determination of the Ultimate Diagnosis and the Follow-up Outcome Status

After the follow-up contact and before any attempts were made to derive the protocol, we determined what we termed the ultimate diagnosis — that is, the best explanation for the chest-pain syndrome that prompted the emergency room visit. The investigators made the ultimate diagnoses on the basis of in-hospital data; the patients' clinical histories since the emergency room visit as obtained from the patients, their physicians, and their hospital records; and, when available, the results of any exercise EKGs or cardiac catheterizations done during the follow-up period. For 11 patients who had been admitted to the hospital, follow-up information clearly contradicted the hospital-discharge diagnosis; all other hospital-discharge diagnoses were accepted as ultimate diagnoses. Unless otherwise stated, the diagnostic criteria for patients not admitted to the hospital were identical to those for admitted patients. Ultimate diagnoses were assigned to one of three categories: acute myocardial infarction, acute ischemic heart disease without infarction, and "other."

All patients admitted to the coronary-care unit had tests for cardiac enzymes, including serum aspartate aminotransferase (SGOT), creatine kinase, and lactic dehydrogenase; EKGs were performed on admission and again at least daily, usually for three more days. Tests for creatine kinase isoenzymes were not performed routinely in all patients but were obtained (usually in preserved specimens with elevated total creatine kinase) when standard enzyme levels were neither normal nor diagnostic of infarction. Because all patients had a chief complaint of chest pain, the ultimate diagnosis of acute myocardial infarction was made if abnormalities were detected in any of the following: serum enzymes — SGOT above the normal and at least twice the admission value, then returning to normal in a patient who did not have intramuscular injections, muscle trauma, or hepatobiliary disease, or creatine kinase MB isoenzyme fraction above 5 per cent of the total creatine kinase, or lactic dehydrogenase isoenzyme 1 greater than isoenzyme 2 in the absence of hemolytic anemia or renal infarction; EKGs — development of new pathologic Q waves (at least 0.04 second in duration) and at least a 25 per cent decrease in the amplitude of the following R wave as compared with that of the emergency room EKG; or scintiscan — focal uptake of technetium-99m stannous pyrophosphate in the cardiac area if the serum enzyme peak might have occurred before hospitalization and if the patient had no prior history of myocardial infarction or valvular calcification. The diagnosis of acute myocardial infarction in a nonadmitted patient was made if the foregoing criteria were met or if a follow-up EKG showed new pathologic Q waves not related to an acute myocardial infarction diagnosed on an acute presentation subsequent to the emergency room visit.

We made the ultimate diagnosis of acute ischemic heart disease without infarction if myocardial infarction was not diagnosed and two additional criteria were met: the first was that the diagnosis of angina was made in the hospital by the senior clinician associated with the case and was not contradicted by follow-up information or that it was based on a positive exercise test, a positive coronary arteriogram, or the follow-up history; the second was that the patient's original emergency room chest-pain syndrome was either new or worse (in frequency, severity, or duration) than any chronic anginal syndrome, regardless of whether the new or worsening pain was precipitated by heart failure, arrhythmias, or other conditions.

Because admitted patients had more diagnostic tests than nonadmitted patients, the number of myocardial infarctions may be underestimated in the nonadmitted group. Nevertheless, because we determined the six-month outcome in 99.2 per cent of patients, our follow-up was considered adequate to identify any nonadmitted patient whose myocardial infarction or acute ischemic heart disease without infarction would have been better treated in the hospital.

### Statistical Methods

Sensitivity was determined by dividing the number of true-positive diagnoses by the number of patients with the disease. Specificity was determined by dividing the number of true-negative diagnoses by the number of patients without the disease. To determine positive predictive value, the number of true-positive diagnoses was divided by the sum of the number of true-positive diagnoses plus the number of false-positive diagnoses.

To construct a model capable of identifying acute myocardial infarction, we analyzed all information available in the emergency room by several statistical techniques. Missing data were considered in two ways: as missing and then as negative. The results of both analyses were similar. Neither stepwise multivariate linear discriminant analysis[5] nor multivariate logistic regression analysis[6] yielded identifications more accurate than those of the house officers.

We then used a recursive partitioning approach to classification.[7-11] The purpose of this approach was to divide patients into subgroups, each of which ideally would consist entirely either of patients with infarctions or of patients without infarctions. We began by analyzing the ability of each potential predictive variable (elements of the history, physical examination, and so forth) to discriminate patients with myocardial infarction from patients without it. For continuous variables (e.g., systolic blood pressure), we determined which value (e.g., 150 mm Hg) was the best discriminator. On the first step of the partitioning process, we defined the best variable as the one that provided the maximum reduction in "diversity."[8,12] Diversity, in its mathematical definition, is based on the probability of a diagnosis and on the relative penalties associated with a false-positive versus a false-negative diagnosis. Thus, for any group of patients, diversity = ((the probability of having had an MI [myocardial infarction] and being in the subgroup) × (the penalty of a false negative) × (the probability of a false negative)) + ((the probability of not having had an MI and being in the subgroup) × (the penalty of a false positive) × (the probability of a false positive)). The penalty terms in this equation are important for their relative and not for their absolute values, and they can be defined arbitrarily by the investigators. For example, one might decide that the penalty for a false-negative diagnosis was 10 times the penalty for a false-positive diagnosis, and one would thus use the values 10 and 1 in the diversity equation.

Because neither physicians nor any computer protocol can be expected to determine perfectly in every case whether or not a patient is having an acute myocardial infarction, a shift in the criteria to increase sensitivity in any decision-making system typically also decreases specificity.[13] We tried many different relative-penalty values, but we always assumed that the medical cost of a false-negative diagnosis (i.e., sending home one patient with infarction) outweighed the dollar costs of a false-positive diagnosis (i.e., admitting one patient without infarction). Because the choice of specific relative penalties is based on an arbitrary value judgment, we selected the computer protocol and the relative penalties that, in the retrospective analysis of data, provided 100 per cent sensitivity at the highest possible specificity and remained as accurate as possible in a bootstrap estimate of bias.[14,15]

After we chose the single best discriminating variable, we divided patients into two subgroups. In our analysis, the presence of certain EKG findings was the best predictive variable (Fig. 1). Then, each of the resulting subgroups was treated as a separate sample and, if further partitioning proved useful in separating patients with infarction from patients without it, could be divided again using the next best variable.[8,9] In our analysis, patients with ST-segment elevation or Q waves that were both suggestive of infarction and not known to be preexistent could not benefit from further analysis, whereas patients without such EKG findings could be further subdivided. Each subgroup could be divided again and again using subsequently chosen variables or different values of previously chosen continuous variables until no further partitioning was beneficial.

Although this method would normally select variables on the basis of empirical evidence only, we also required that selected variables have a priori clinical relevance; given a choice, we favored clinical over mathematical considerations. For example, if the variable "brown hair" were selected by the analysis, we would discard it as having no clinical relevance. We would then repeat the analysis, even though the variable that would now substitute for "brown hair" would not be as accurate in the retrospective classification of patients.

Our recursive partitioning technique resulted in the algorithm shown in Figure 1. This algorithm classified a patient as probably having had an infarction if the patient was in a terminal subgroup (i.e., a subgroup with no further subdivisions) in which the probability of an infarction was one in 15 or higher and as not having had an infarction if the probability was less than one in 15.

### Phase Two, Validation Testing

The computer model (protocol) was prospectively evaluated in two sets of patients at the Brigham and Women's Hospital: an emergency room validation set of 357 patients seen between October 1980 and August 1981, and a separate admission validation set of 111 patients admitted in 1978.

#### *Emergency Room Validation Set*

The methods for this phase were identical to those used at Yale–New Haven Hospital except that the entry age was reduced to 25 years and patients were excluded if they did not sign informed-consent forms in which they agreed to return in 48 to 72 hours for another test of cardiac enzymes and an EKG. About 80 per cent of nonadmitted patients agreed to the study design, 85 per cent of the consenting nonadmitted patients returned for follow-up, and the remainder were known to be alive and well at least one week after discharge. The emergency room data form was shortened to eliminate variables that had been unhelpful in the Yale data set. Most of the forms were completed by the emergency room house officer, but some were completed by a research nurse who had no knowledge of the variables in the computer protocol. The nurse routinely obtained all information from either the emergency room physician or the physician's note, although on rare occasions historical information was obtained from the admitting house officer. One of us (L.G.) rechecked all EKG reports. If the emergency room physician reported 1 mm or more of ST-segment elevation that was neither known to be preexistent nor specifically described as early repolarization, the ST-segment elevation was considered suggestive of infarction. If the EKG report was questionable or if the principal investigator and the nurse disagreed, the EKG report was reviewed independently by three physicians who had no knowledge of the computer protocol or of the patient's diagnosis. Although the formal hospital EKG reading was also obtained, the emergency room physician's reading was used as it had been used in phase one. Creatine kinase isoenzymes were measured electrophoretically during most of phase two; creatine kinase MB isoenzymes were considered indicative of infarction if detected in more than trace amounts. Each patient's ultimate diagnosis was established without knowledge of the prediction of the computer model.

#### *Admission Validation Set*

The charts of 111 patients admitted with a chief complaint of chest pain during 1978 were reviewed by two physicians and a nurse who had no knowledge of the variables in the computer protocol. Data were extracted as described above from the notes of the emergency room physician or the admitting house officer. This second validation set allowed us to compare the performance of the protocol with that of the house officers at a time when their behavior could not have been influenced by our study.

## Results

### Yale House Officers' Emergency Room Decisions

The emergency room physicians at Yale recommended admission to the coronary-care unit to 211 (44 per cent) of the 482 patients because of a tentative diagnosis of acute myocardial infarction or a decision to rule out infarction. Admission to the coronary-care unit was recommended to 200 (99 per cent) of the 202 patients in whom the house officers estimated the probability of myocardial infarction to be above 5 per cent or the probability of acute ischemia to be above 25 per cent. Conversely, admission was recommended to only 11 (4 per cent) of the 280 patients whose estimated probabilities were lower. Of the 211 for whom admission was recommended, three patients refused admission, and four others were sent home by their private physicians; thus, 204 patients were admitted to the coronary-care or intensive-care unit and were defined as coronary-care-unit admissions. In another 264 patients (55 per cent), the emergency room physician recommended against admission, and all such patients were sent home. The remaining seven patients (1 per cent) were admitted to non-intensive-care areas on the basis of tentative diagnoses that did not include acute infarction and for reasons other than to rule out infarction; for the purposes of this study, these patients were defined as nonadmissions.

### Yale Ultimate Diagnoses and Follow-up Outcomes

#### *Coronary-Care-Unit Admissions*

Of the 204 patients admitted to the coronary-care unit, 58 (28 per cent) had acute myocardial infarctions (38 transmural and 20 nontransmural infarctions). An additional 65 patients (32 per cent) had acute ischemic heart disease without infarction; none of the 65 had ventricular fibrillation, but five had uncontrollable

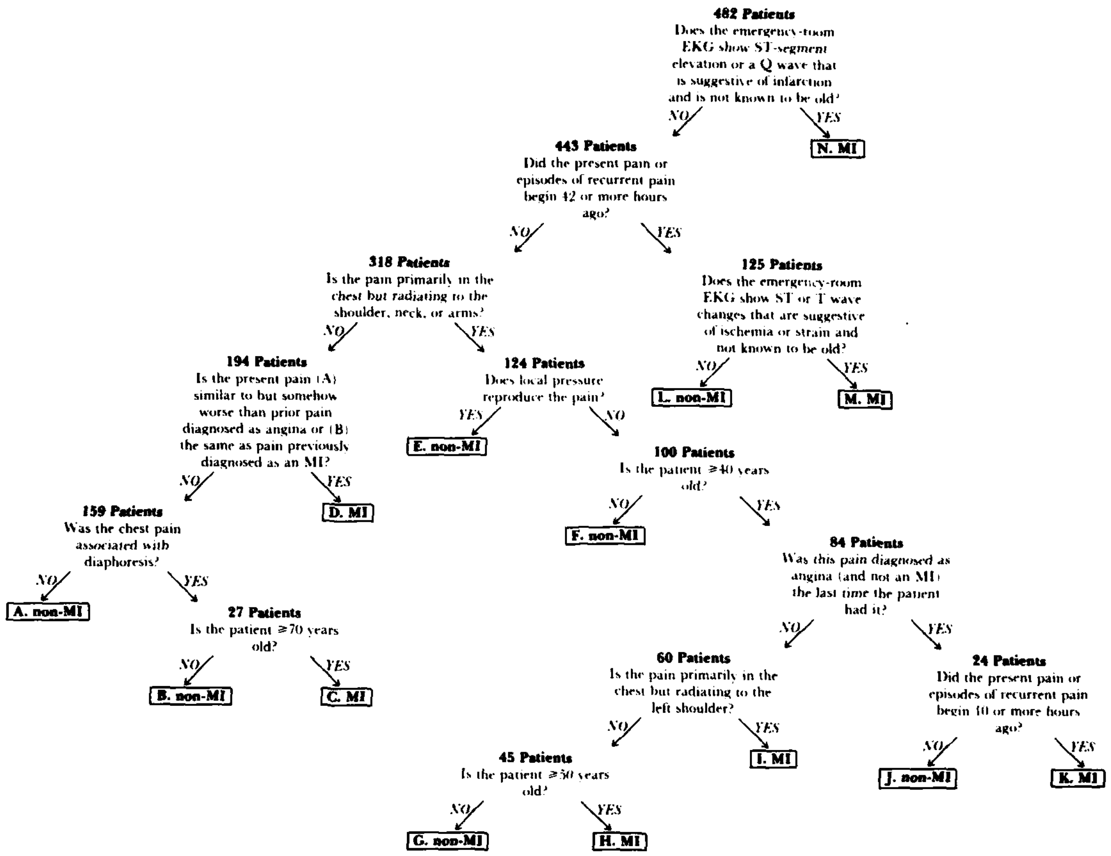


Figure 1. Computer-Derived Decision Tree for the Classification of Patients with Acute Chest Pain.

Each of the 14 letters (A through N) identifies a terminal branch of the tree. For any given patient, start with the first question regarding ST-segment elevation and then trace the patient through the relevant subsequent questions until a terminal branch is reached. In the Yale–New Haven Hospital sample, seven terminal branches (C, D, H, I, K, M, and N) contained all 60 patients with acute myocardial infarction as well as 28 patients with unstable angina and 43 patients with other ultimate diagnoses. For a breakdown of all terminal branches, see Table 3.

ER denotes emergency room, EKG — electrocardiogram, and MI — myocardial infarction.

pain that led to the decision to perform urgent coronary-artery bypass surgery. The remaining admitted patients (40 per cent) had other ultimate diagnoses: pericarditis (six patients), severe congestive heart failure (six patients), primary arrhythmia (atrial in three patients and ventricular in one), aortic stenosis (four patients), stable angina (10 patients), and noncardiac conditions (51 patients).

### Nonadmissions

Of the 278 patients not admitted, two (1 per cent) were ultimately diagnosed as having presented with acute myocardial infarctions; they were therefore considered as representing inappropriate nonadmissions. Another eight patients (3 per cent) had not been admitted despite syndromes that were ultimately diagnosed as representing acute ischemic heart disease without infarction. Four of the patients not admitted — one who had acute ischemia without infarction and three others — died from cardiac causes during the follow-up period. However, because none of these deaths occurred within three months of the emergency room visit and because all four patients had had visits with their regular physicians during the interval between the emergency room visit and the follow-up, no deaths could be attributed to nonadmission. None of the seven patients who went home even though an emergency room physician recommended admission had myocardial infarction or retrospective evidence of acute ischemia.

Although we did not measure cardiac enzymes or perform EKGs in all 278 patients in the nonadmission group, the rate of clinical follow-up by the patients' own physicians was high: 186 patients (67 per cent) saw a physician during the follow-up period, including 117 (83 per cent) of the 141 patients in whom the emergency room chest-pain syndrome persisted or recurred and 69 (50 per cent) of the 137 patients in whom it had not. Of the 24 patients with persistent or recurrent symptoms who had no subsequent follow-up visit to a physician, the only patient who had definite or probable angina on our study follow-up contact had angina that had been diagnosed before his emergency room visit.

### Prediction of the Ultimate Diagnosis at Yale–New Haven Hospital

#### *Physicians' Probability Estimates*

The emergency room physicians tended to overestimate the likelihood of acute myocardial infarction in the "higher-probability" patients (Table 1). Note that 44 (73 per cent) of the 60 myocardial infarctions occurred in the 75 patients judged to have the highest risk; included were 34 infarctions among 39 patients with ST-segment elevation or Q waves not known to be preexistent. The remaining 14 admitted patients with infarctions were among a group of 144 patients whose probabilities of infarction were estimated to be intermediate.

#### *Computer Model*

Using the recursive partitioning technique, we constructed a simple flow diagram that immediately segregated patients with apparently new ST-segment elevation or Q waves into a high-probability terminal subgroup (Fig. 1). Then, the computer protocol classified the other patients, using the presence or absence of new ischemic ST-segment or T-wave changes and seven other clinical factors (Table 2) in a branching logic that seemed to reflect conventional clinical wisdom. For example, pain that had begun 42 hours or more earlier did not represent acute infarction unless it was accompanied by changes in the EKG, whereas pain that had begun 10 or more hours earlier was more likely to represent infarction in patients in whom previous similar pains had been diagnosed as angina. In addition, the radiation of pain to the neck, shoulder, or arms was correlated with infarction only if it was not accompanied by local tenderness.

The best computer-decision protocol retrospectively classified 143 patients as having had acute myocardial infarctions: included were all 60 patients with acute myocardial infarctions (Table 3), 33 patients with acute ischemic heart disease without infarction, and 50 patients with other ultimate diagnoses. Of the 11 patients not admitted in whom the protocol suggested infarction, two did have acute infarcts. Overall, the computer protocol retrospectively achieved a sensitivity of 100 per cent for acute infarction, with a specificity of 80 per cent (339 of 422) and a positive predictive value of 42 per cent (60 of 143).

**Table 1. Relation between Probability Estimates of Yale–New Haven Hospital Emergency Room Physicians and the Likelihood of Acute Myocardial Infarction (MI).**

| Probability Estimated by the Physician | No. of Patients | No. of Known Infarctions |
|---|---|---|
| Probability of MI >75% | 75 | 44 (59)* |
| Probability of MI 25–75% | 43 | 4 (9) |
| Probability of MI 6–24% | 49 | 4 (8) |
| Probability of MI ≤5%, and probability of acute ischemia ≥25% | 35 | 4 (11) |
| Probability of MI ≤5%, and probability of acute ischemia 6–24% | 17 | 2 (12) |
| Probability of MI ≤5%, and probability of acute ischemia ≤5% | 263 | 2 (0.8) |

*The numbers in parentheses are percentages.

### Prospective Validation, Brigham and Women's Hospital

On the basis of our original premise, which placed a patient in a myocardial-infarction subgroup if the probability of infarction was at least one in 15, virtually all the branches of the computer protocol performed well in the validation testing (Table 3). The only exception was in subgroup G: although noninfarction was predicted in this subgroup, one of the 12 patients at Brigham and Women's Hospital had an infarction.

During the emergency room validation phase, the computer protocol was as accurate in identifying infarction as were the house officers making decisions about the admission to the coronary-care unit (Table 4). In contrast to the triage patterns at Yale, the house officers at Brigham and Women's Hospital also admitted 29 patients with suspected infarctions to nonintensive-care areas, because beds in the coronary-care and intensive-care units were in limited supply and because the patients' likelihood of having had an acute infarction was deemed to be relatively low; three (10 per cent) of these 29 patients had infarctions. In addition, two other patients with infarction were sent home by the house officers. If the computer protocol were integrated with the physicians' recommendations in such a way that intensive-care admission would be reserved for patients in whom the protocol predicted infarction and the physician recommended admission

**Table 2. Summary of the Nine Important Clinical Factors Identified by the Recursive Partitioning Decision Protocol (see Fig. 1).**

**History of present illness**

- How old is the patient?
- How long ago did the present pain or episodes of recurrent pain begin?
- Is the pain primarily in the chest but radiating to the shoulder, neck, or arms?
- Was the chest pain associated with diaphoresis?

**Past medical history**

- If the patient was ever told that this same pain was angina, is the present pain somehow worse? *or* Is the present pain the same as pain that was previously diagnosed as an acute myocardial infarction?
- Was this pain called angina (and *not* a myocardial infarction) the last time the patient had it?

**Physical examination**

- Does local pressure reproduce the pain?

**Electrocardiogram**

- Does the emergency room EKG show ST-segment elevation or definite Q waves that are suggestive of acute infarction and are not known to be old?
- Does the emergency room EKG show ST-segment or T-wave changes that are suggestive of ischemia or strain and are not known to be old?

(either to intensive care or to another hospital area), the sensitivity for admitting patients with infarctions to intensive care would be virtually maintained, and the specificity and overall accuracy would be markedly improved (Table 4).

The value of the computer protocol became even more evident when the two validation sets were combined. The protocol alone correctly identified 80 of 85 patients with infarction, whereas only 78 of these patients were actually admitted to intensive care. Infarctions occurred in five (10 per cent) of the 48 patients judged to be at low risk and admitted to non-intensive-care areas by the physicians — a percentage that was consistent with the 12 per cent infarction rate among patients judged to be at low risk who were admitted to the coronary-care unit at Yale–New Haven Hospital. Among the patients in whom the computer protocol suggested infarction, infarctions occurred in 74 (47 per cent) of 157 who were admitted to intensive care, in five (17 per cent) of 29 who were admitted to other areas, and in one (4 per cent) of 23 who were not admitted. Conversely, among the patients in whom the protocol suggested noninfarction, infarction occurred in only four (5 per cent) of 84 admitted to intensive care, in none of 19 admitted to other areas, and in one (0.6 per cent) of 156 not admitted. Most notably, a combination of the decision of the computer protocol with the recommendations of the physicians was again more accurate than either alone (Table 5). Also noteworthy if non-intensive-care admission is to be considered for some low-risk patients is the fact that the integration of the model and the physicians' judgments identified a group of 107 patients among whom only 5 per cent had acute infarctions; this rate was lower than that in any subgroup of low-risk admitted patients that could be identified by the physicians at Yale–New Haven Hospital or Brigham and Women's Hospital.

The advantages realized by integrating the protocol with the physicians' judgments suggest that the two tended to miss different patients. For example, only one patient with an infarction was both missed by the protocol and not admitted to intensive care by the house officers. The protocol was accurate in identifying 38 patients in Subgroups A and B who were admitted to intensive care but of whom only one patient had an infarction; in these cases, the physicians appeared to place too much importance on the patient's qualitative description of the pain. Conversely, the house officers performed slightly better than the protocol in Subgroups G, H, and I. Both the protocol and the house officers had difficulty in patients with prior angina or infarction (Subgroups D, J, and K), but in all three subgroups the protocol was more accurate than the physicians in terms of our goal of admitting patients to intensive care if the chance of infarction was above one in 15.

**Table 4. Results of the Brigham and Women's Hospital Emergency Room Validation Phase.***

| Result | Computer Model Predicts Infarction | Physicians Admit Patient to Coronary-Care Unit | Computer Model Integrated with Physicians † |
|---|---|---|---|
| Sensitivity for infarction | 50/55 (91) | 50/55 (91) | 49/55 (88) |
| Specificity for non-infarction | 211/302 (70) | 203/302 (67) | 233/302 (77) ‡ |
| Overall accuracy | 261/357 (73) | 253/357 (71) | 282/357 (79) § |

*Figures in parentheses are percentages.

†Myocardial infarction is predicted if computer model predicts infarction and physicians admit patient to the coronary-care unit or to any other type of hospital bed.

‡Compared with physicians alone in a matched analysis of discordant pairs, chi-square = 15.0; P<0.01.

§Compared with physicians alone in a matched analysis of discordant pairs, chi-square = 12.6; P<0.01.

**Table 3. Breakdown of Patients in Each of the 14 Terminal Branches of the Decision Tree (see Fig. 1).**

| Terminal Branch | No. of Acute Infarctions/No. of Patients in Terminal Subgroups | | | Total |
|---|---|---|---|---|
| | Yale Training Set | B&W ER † Validation Set | B&W Admission Validation Set | |
| A | 0/132 | 2/84 | 0/13 | 2/229 (1) ‡ |
| B | 0/20 | 0/19 | 0/9 | 0/48 |
| C * | 2/7 | 1/3 | 0/1 | 3/11 (27) |
| D * | 4/35 | 4/37 | 5/12 | 13/84 (15) |
| E | 0/24 | 0/12 | 0/1 | 0/37 |
| F | 0/16 | 0/12 | 0/1 | 0/29 |
| G | 0/13 | 1/7 | 0/5 | 1/25 (4) |
| H * | 9/32 | 4/10 | 4/16 | 17/58 (29) |
| I * | 8/15 | 1/15 | 1/6 | 10/36 (28) |
| J | 0/19 | 1/18 | 0/8 | 1/45 (2) |
| K * | 2/5 | 1/9 | 0/3 | 3/17 (18) |
| L | 0/115 | 1/64 | 0/6 | 1/185 (1) |
| M * | 1/10 | 4/16 | 0/6 | 5/32 (16) |
| N * | 34/39 | 35/51 | 20/24 | 89/114 (78) |

*All patients in this terminal branch would be classified as having had acute myocardial infarctions by the computer-derived decision tree.

†B&W is Brigham and Women's Hospital; ER is emergency room.

‡The numbers in parentheses are percentages.

## Discussion

Despite continuing debate over the precise value of coronary-unit care in decreasing mortality,[16,17] patients suspected of having acute myocardial infarctions are usually triaged on the basis of a clinical credo that emphasizes the hazards of inappropriate nonadmission. Unstable angina is difficult to distinguish from infarction in the emergency room and carries a worrisome short-term prognosis,[2,18-20] especially if it is manifested by prolonged pain and EKG changes,[2] or if the patient continues to have symptoms after 24 hours in the hospital.[20] Using our liberal definition of acute ischemia without infarction, less than 10 per cent of such patients at both hospitals had complications requiring intensive care, and none had acute problems without first having had progressive or persistent symptoms that would have allowed time for their transfer to intensive care. Thus, although recognition and treatment of patients with beginning or worsening angina are mandatory, many patients assigned this diagnosis would not require admission to coronary-care units if it could be reliably determined that they were not having acute myocardial infarctions.

Our follow-up of emergency room patients from two hospitals revealed that medical house officers responded appropriately to the established credo: 97 per cent of patients with myocardial infarction were admitted to the hospital. Although our follow-up procedures could have missed some nonadmitted patients who had acute myocardial infarctions without clinical sequelae or subsequent EKGs, any such additional missed diagnoses had no impact on patient outcome.

Unfortunately, the emergency room physicians' high sensitivity for admitting patients with myocardial infarctions was achieved by recommending admission for patients estimated to be at relatively low risk. The tendency for physicians to overestimate the probability of infarction in patients admitted in order to rule out infarction was consistent with the finding that physicians usually overestimated the probability that x-ray findings would be positive.[21] The 28 per cent rate of myocardial infarction for all patients admitted to Yale–New Haven Hospital and the 15 per cent rate for patients admitted to Yale–New Haven Hospital without ST-segment elevation or new Q waves on their emergency room EKGs were remarkably similar to the rates found in other recent studies.[2,4,22] Even at Brigham and Women's Hospital, where some supposedly low-risk patients were admitted to non-intensive-care areas, the respective infarction rates for intensive-care admissions were 32 per cent and 14 per cent.

**Computer Modeling to Diagnose Acute Myocardial Infarction**

Several previous studies have used such multivariate techniques as linear discriminant analysis,[23,24] logistic regression analysis,[4] and a modified Bayesian approach[25] to predict the cause of acute chest pain. In each of these statistical techniques, an individual factor in the calculation of risk is assigned the same weight for all patients unless complex interaction variables are introduced into the model. However, such a fixed weighting is not necessarily valid in complex medical decision making, since in some patients a single overwhelming factor may make all other factors trivial, certain factors may be important only in the presence of other factors, and certain factors may have a direct correlation in some patients and an inverse correlation in others. Furthermore, these techniques commonly assume that all misclassifications are equally bad, whereas the cost function in recursive partitioning permitted us to accept 14 false-positive predictions of infarction to avoid one false-negative prediction.

Although differences in statistical techniques preclude a direct comparison among previous studies and the present report, previous studies have cited the patient's age,[24,25] the location of the pain,[4,23] a prior diagnosis of angina pectoris or myocardial infarction,[4] and the length of the pain episode[23] as predictive of infarction. The EKG has also been found to be helpful in prior univariate[22] and multivariate[4,23-25] analyses, although the definitions of electrocardiographic criteria have varied. It is notable that the physical examination is rarely helpful in predicting the cause of acute chest pain, unless local palpation is found to reproduce the pain. Such epidemiological risk factors as smoking, hypertension, hyperlipidemia, and family history have been relatively unimportant in all series, apparently because other historical or EKG characteristics are more predictive of acute myocardial infarction in an individual patient. Measurements of cardiac enzymes obtained in the emergency room were helpful in one study[25] but not in another,[26] and future analyses should try to validate prospectively the possibility that enzyme determinations might be valuable in some patients.

Earlier authors have suggested that the care of patients with suspected or documented infarctions could be made more cost-effective by means of early discharge from the hospital of patients with uncomplicated infarctions[27,28] or early discharge from intensive care of patients who have a low risk of complications.[29,30] Our study, like that of Pozen et al.,[4] attempted to improve diagnostic accuracy for patients who go to an emergency room. Pozen and his colleagues found that the positive predictive value of the emergency room diagnosis of acute ischemic heart disease (defined as myocardial infarction or unstable angina pectoris) in patients with any of 10 different chief complaints increased from 49 per cent to 67 per cent when a computerized analysis was calculated for physicians at the time of emergency room triage. This improved positive predictive value, which apparently could not have been achieved by their computer model alone, was achieved by improving the diagnosis for

**Table 5. Integration of the Computer Model* with the Physicians at Brigham and Women's Hospital: Combined Emergency Room and Admission Validation Sets.**

| Myocardial Infarctions | Physicians' Actual Decisions † | Computer Model Integrated with Physicians †‡ |
|---|---|---|
| Among patients admitted to the CCU | 78/241 (32) | 79/186 (42) |
| Among patients admitted to other hospital beds | 5/48 (10) | 5/107 (5) |
| Among patients not admitted | 2/179 (1) | 1/175 (0.6) |

*To be compared with actual triage decisions. The integration of the model and the physicians states that a patient would *(1)* be admitted to the coronary-care unit (CCU) if the computer model predicted myocardial infarction (MI) *and* the physician recommended hospital admission to the CCU or to another hospital bed; *(2)* be admitted to another hospital bed if the physician recommended CCU admission but the model did not predict MI, or if the model predicted MI and the physician recommended that the patient be sent home; and *(3)* be sent home if the model predicted non-MI and the physician did not recommend admission to the CCU.

†Figures in parentheses denote percentages.

‡The integration of the model with the physicians was significantly (chi-square with 4 degrees of freedom = 31.5; $P<0.01$ by the marginal homogeneity test) more accurate than the physicians alone, because it kept more patients without infarction out of the CCU, and it had a significantly ($P = 0.016$) higher positive predictive value among patients admitted to the CCU.

patients whose estimated probabilities of having acute ischemic heart disease were less than 50 per cent. Our protocol alone was as good as our doctors at recognizing high-risk patients. More important, when we integrated our protocol with the physicians' recommendations sensitivity was maintained at a significantly higher specificity ($P<0.01$) and positive predictive value ($P = 0.016$ by chi-square test). In addition, our protocol allows a physician to use a simple flow diagram to ascertain whether a patient is likely to have an infarction, without having to rely on a calculator or the help of a research assistant.

### Implications

Although our computer protocol performed well in external validation testing at a second hospital, substantially more testing will be required before it can be applied confidently to clinical practice. Some of the protocol's current branch points were arrived at on the basis of a very small number of patients with infarction, and the protocol may be modified, lengthened, and improved on the basis of experience with a larger number of patients. For example, Subgroup G did not fare so well in prospective testing, and we would hope that an increase in sample size would allow more accurate predictions among patients in Subgroups G, H, and I. In addition, a pooled analysis of patients from all three data sets indicates that patients in Subgroup D had a very low risk of infarction if their pain lasted for less than 25 minutes and was not accompanied by EKG changes. Of course, any modification of the model along these lines will require prospective validation.

The use of the protocol — which is always subject to being overridden by the physician — may sometimes lead to more rapid triage decisions and the earlier use of monitors and prophylactic lidocaine during the high-risk early phase of infarction.[31,32] However, in our hospital, most of the delay in instituting antiarrhythmic prophylaxis and physical transfer to intensive care is related to practical problems and not to delayed decision making.

As shown in Table 5, the wisest clinical application of the protocol will probably be to complement rather than to substitute for conventional clinical judgment. The integration of the model with physicians' judgments may achieve two goals: It may prevent the inappropriate nonadmission of some patients with infarctions, and it may identify a group of patients whose relatively low chance of infarction may permit admission to non-intensive-care areas. Because any such changes in decision making will have important implications for cost effectiveness, further prospective testing will be required before the protocol can be recommended for routine use.

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